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التاريـــخ: / /

نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

أنا الطالب: أماني محسن يوسف حمريوش الرقم الجامعي: (٨٠٨٠١٩٠)

تخصص: الجيولوجيا الكليـــــة: العلوم

عنوان الرسالة: Late Cretaceous (Muwaqqar Formation) Ammonites in southern Jordan

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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LATE CRETACEOUS (MUWAQQAR FORMATION) AMMONITES IN SOUTHERN JORDAN

By
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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Geology

Faculty of Graduate Studies
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May, 2011

COMMITTEE DECISION

This thesis (Late Cretaceous (Muwaqqar Formation) Ammonites in southern Jordan) was successfully defended and approved on May 10, 2011.

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Dedication

To my Parents, sisters (Ahlam and Manar), brother (Mohamed),

and to Emad.....

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My gratitude is endless for my parents, sisters, brother and my husband (Emad) for their moral support, care and patience.

Table of contents

List of Tables

List of Figures and Plates

List of Figures and Plates cont.

List of Figures and Plates cont.

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ABSTRACT

Micro-, macro- paleontology, microfacies and paleoenvironment study was carried out in Jibal Ghuzayma (30 33 N, 36 20 E), which are located 160 km (aerial) south east Amman and 50 km ESE Jurf Al Darawish. The field work was mainly concentrated on measuring the stratigraphic columnar section and sampling of the encountered macrofossils, and carbonate rock supply for the microfacies analysis from 33 m thick section of the Muwaqqar and Um Rijam Formations.

Five microfacies types were identified in the studied samples. The majority of these microfacies types are phosphatic foraminiferal micrite (wackestone-packstone), foraminiferal phosphatic micrite (packstone) and foraminiferal micrite (packstone). Generally, indicating deposition in deep-water basin with low oxygen. The presence of large quantity of planktonic foraminifera, micrite and phosphate particles in Muwaqqar Formation compared with Al-Hisa and Amman Formations below indicates sea level rise.

Two planktonic foraminifera (Heterohelicidae and Rotaliporidae?) and one benthonic family (Buliminidae) were recorded from the study area. Three species of Ammonite were identified, they belong to ***Spenodiscus lobatus*** (Tuomy, 1856), ***Libycoceras ismaeli*** (Zittel, 1895) and *Baculite sp.* (Lamark, 1799), they indicate Maastrichtian age.

Chapter one

introduction

1.1 Upper Cretaceous rocks in Jordan:

Because of its proximity to the Arabian Shield, Jordan was sporadically submerged with marine water. Throughout the Paleozoic, in general, marine strata are restricted to the Ordovician and Silurian. Other periods are either missing or represented by terrestrial sediments (Bender, 1974; Powell, 1989a).

The Mesozoic was not much better. Triassic and Jurassic strata are restricted to northern Jordan. Tethys Ocean was unable to penetrate deeper into central and southern Jordan, thus leaving the majority of the country devoid of the rocks of these two periods (Bandel and Khouri, 1981; Andrews, 1993). The Early Cretaceous was dominated by fluvial sandstone regime throughout the country with a few marine intercalations in its northern most part (Abed, 1982; Amireh, 1999).

The upper Cretaceous includes the following ages (Cenomanian – Maastrichtian (100 – 65.5 ma)) which represented in Jordan by Ajlun Group and the lower part of the Belqa Group, the upper part of the Belqa Group extend to the Tertiary (Eocene) (Abed, 2000).

By the onset of the Cenomanian (early late Cretaceous), a global marine transgression took place, and the whole Eastern Mediterranean become submerged. Jordan becomes part of the shallow, epeiric, tropical Tethys continental shelf and consequently, the scene for carbonate

production and deposition. This essentially carbonate regime continued from the Cenomanian throughout the Eocene, a duration of around 65 million years with the deposition of more than 1000 m of carbonate and associated sediments in north Jordan which are decreasing to the south and southeast (Powell, 1989b; Abed 2000).

This carbonate regime has been subdivided into two groups: lower (Ajlun Group) and upper (Belqa Group) (Powell, 1989 b). The Ajlun Group is of Cenomanian – Turonian age. It consists of alternating limestone/dolomite and marl horizons of varying thicknesses. Some of these horizons are highly fossiliferous (Burdon, 1959).

The Belqa Group overlies the Ajlun Group and extends from the Coniacian through the Eocene. It consists of marl, chalk, chert, phosphate and oil shale with limestone. The deposition of chert, phosphate and oil shale indicate prevailing cold upwelling currents of the Tethys in the north onto its southern continental shelf, which led to their deposition. These conditions remained the same until about upper Eocene when the whole Eastern Mediterranean was uplifted and the Tethys Ocean regressed from the area (Powell, 1989b; Abed and Sadaqah, 1998; Abed, 2000).

One geological event is worth noticing. Jordan, as a part of the Eastern Mediterranean, was affected during the late Cretaceous and especially during the Maastrichtian by a compressional event, represented by the Syrian Arc Fold system, resulting from the movement of Africa and Arabian plates to the north (Krenkel, 1924; Bowen and Jux, 1987; Abed, 1989). The compressional forces developed variations in the continental shelf floor relief, producing highs and lows. This paleotopography and the presence of upwelling

currents led to deposition of large amounts of phosphate and oil shale in the basins (Abed and Sadaqah, 1998).

The upper Cretaceous rocks are very rich in macro- and micro-fossils; Ajlun Group contains oysters and other bivalvia, gastropoda, echinoidea, cephalopoda (ammonites), corals and foraminifera (Makhlouf *et al*. 1996). Belqa group contains ammonites, Baculite *sp*. nautiloidea, bivalvia, shark teeth, gastropoda, thalassinoids burrows, fossil wood, bones and bone fragments, skeletal fragments of Terrasaurs and Mosasaurs and foraminifera (Moumani, 2008), nummulites.

1.2 Aims of the research:

The main aim of this thesis is to shed more light on the exact age of Muwaqqar Chalk Marl (MCM) Formation based on biozonation throughout the formation. However, identifying and classifying the ammonites to the species level is another major goal, and to deduce the paleoenvironment of the MCM Formation.

1.3 Rational:

There is not much of specialist in macropaleontology in Jordan, and there is not much interest or concern about this field. So the importance of this work is to bring about specialist in this field, and to illustrate the importance of the macropaleontology in geology science.

1.4 Location and access:

The study area (Jibal Ghuzayma 30 33 N, 36 20 E) is situated 160 km (aerial) to the southeast of Amman and 50 km east-south-east of Jurf Al Darawish (Fig.1.1). The area can be reached from Amman via desert highway then the Suwaqa/Tuba road then Azraq highway.

The area is rather remote, and the nearest settlement to the area is Al Hisa village where Bedouin families settled since some time and the Phosphate City where the workers of the phosphate mines engineers, geologists and others are living.

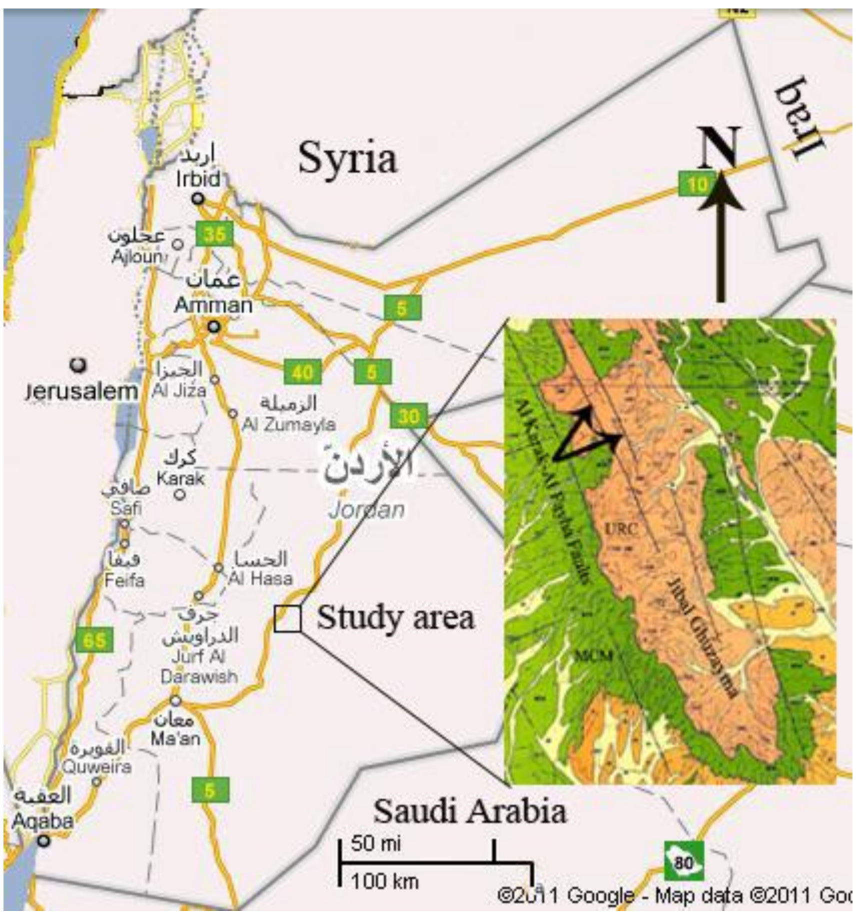


Fig. (1.1): Location map of the study area.

1.5 Climate and vegetation

The study area is situated within a region which experiences a predominantly arid climate. Summers are hot and dry, and winters are cold. Rainfall is between 50-100 mm per annum, and the majority of rainfall is during the main winter months of December, January, February, and March. Evaporation is high. Spars flora typical of the central Jordanian region includes Artemisia, Phlomis, Amygdalus sparticides, Cenopods, and Haluxylon palinornum (Kherfan1987).

1.6 Methodology

1.6.1 Field work

Field work was mainly concerned measuring the geological columnar section and sampling of the encountered macrofossils and carbonate rock supply for the microfacies analysis. Field work was performed in 8 field trips starting in February 2010 and ended in December 2010.

1.6.2 Laboratory work

Laboratory work was concerned about:

1. Preparing thin sections for two types of samples (friable and hard).

2. Photographing the ammonite samples which collected from the study area.

3. Using the polarized microscope to examine the thin sections for microfacies analysis.

1.6.3 Classification basis

Ammonites could be classified according to many characters; the main character is the suture line (most of the ammonites are determined from the shape of the suture line only), shape of the conch, length of the body chamber and ornamentation of the test (it may be ornamented by keels, ribs, nodes, tubercles and spines).

1.7 Ammonites: an overview

Classification of ammonite:

Kingdom - Animalia

Phylum - Mollusca

Class - Cephalopoda

Subclass - Tetrabranchiata

Order – Ammonoidea

Phylum Mollusca:

The Mollusca are soft-bodied invertebrate creatures most of which secrete a hard external shell. They include many familiar living forms like the whelks, the octopus and cuttlefish, but many are known only as fossils (Black, 1978).

Three classes of molluscs are important as fossils, the bivalvia, the gastropoda and the cephalopoda. Most are mobile creatures, living in the sea, but some are found in fresh water, only the Gastropoda occur on land. While externally the molluscan shell is very varied in form, internally the body largely conforms to a basic plan of organization. In general they are bilaterally symmetrical except for the gastropods in which the body is twisted. There are four main parts, the head, the body, the mantle and the foot. Molluscan shell is partly calcareous and partly organic in composition (Black, 1978).

The marine molluscs have a world-wide distribution. A few are found in the deepest parts of the ocean, but the vast majority live on the sea-floor in relatively shallow water. The phylum is abundantly represented in the fossil record since Cambrian times onwards. The molluscs range in size from almost microscopic to gigantic (Black, 1978).

Class Cephalopoda (Leach, 1817)

This class comprises both present-day and fossil forms. Fossil relatives of many of these are known, some of which have long been extinct, for example, clymenias, goniatites, ceratites, ammonites and belemnites. All cephalopods are exclusively marine. They are most abundant in the shallow seas but occur also in the intermediate and even the abyssal depths of oceans. The class was in existence during the Cambrian and has been well represented ever since (Miller and Furnish, 1990).

Cephalopods have a definite head, the mouth being surrounded by a portion of the primitive molluscan foot modified into processes that commonly are either lobelike and bear

tentacles, each with a cirrus, or are armlike and are provided with suckers or hooklets or both. The concrescence of the head and part of the foot to form the so-called head-foot is characteristic of the class, though its name [NL., fr. *cephalo*-+-*poda*] was given because it was believed that the cephalic appendages are used for crawling, which in some forms is true to a certain extent (Miller and Furnish, 1990).

All members of this class have hard parts, but only the shells were commonly preserved as fossils. The shell, which is univalved, is external in *Nautilus* and presumably was borne in similar manner in the many fossil nautiloids and ammonoids. However, it is internal in the other present-day cephalopods, as it was in their fossil kin, including the belemnites. The external shells can be thought of as more or less modified hollow cones which are straight, curved, or coiled (generally in a single plane). These shells are divided by septa into chambers pierced by a tube called the **siphuncle** (Miller and Furnish, 1990).

Many of the external shells of ancient cephalopods are among the best index fossils because their rapid and diverse evolution, widespread occurrence, abundance, and ease of identification even when incomplete and when preserved only as internal molds. Because these shells were relatively light in weight and contained **camerae** that presumably were buoying gas chambers, it was possible for the animals which bore them to rang widely in the shallow seas and some of them may well have crossed the oceans; as a result, many genera and possibly some species are common to the eastern and western hemisphere (Miller and Furnish, 1990).

In 1832 Owen divided the Cephalopoda class into two groups (sub class): Tetrabranchiata (including Nautiloids and Ammoniods) and Dibranchiata (including Belemnites and other living Cephalopoda) in accordance with number of gills (Miller and Furnish, 1990).

Order Ammonoidea (Zittel, 1884)

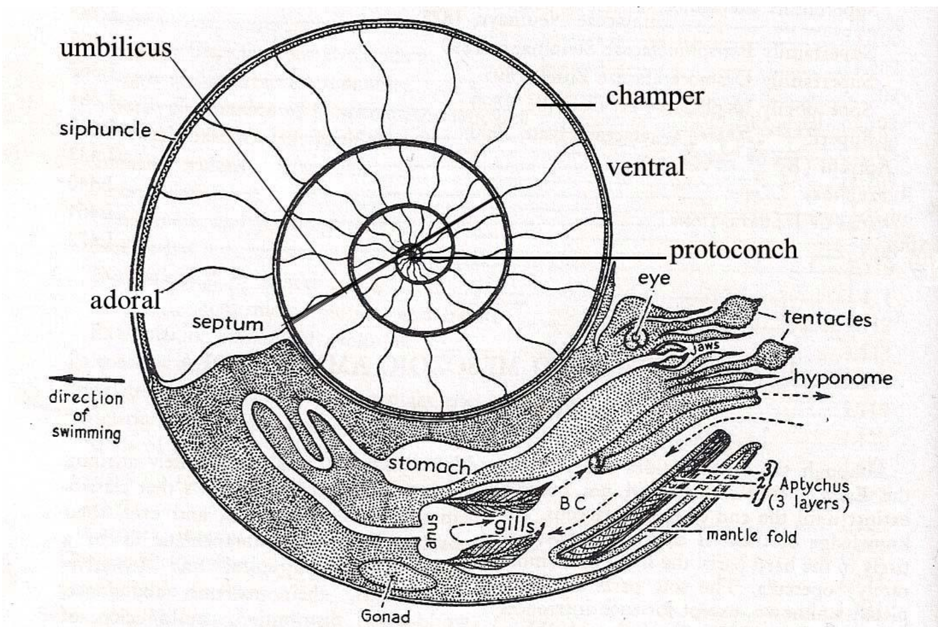


Fig. (1.2): Section of ammonite shell in the plane of coiling, showing morphological features (Arkell, 1990).

The clymenias, goniatites, ceratites, and ammonites, which together constitute the Order Ammonoidea, have long been extinct, but their fossilized shells are common in all continents and many oceanic island. Numerous specimens are remarkably well preserved, even spectacular, and their exceptional value as a basis for stratigraphic correlations has been recognized for well over a century (Miller and Furnish, 1990)

Almost all our knowledge of these creatures comes from studies of the shells and enclosing matrices, but a few opercula are also preserved. The shells are comparable to that of modern *Nautilus*, a presumed relative of the group (Miller and Furnish, 1990)

The present-day representatives of the subclass live in the moderately shallow water of the southwest Pacific Ocean. However, their ancient relatives ranged in the oceans and the seas all over the world, most of the known fossil remains coming from rocks that represent shallow-water marine deposits. The subclass made its debut in the Cambrian. It developed and evolved so rapidly that in the Ordovician it was perhaps the pre-eminent group of animals, some of its members attaining enormous proportions and being the largest creatures of the time. It continued unabated in the Silurian, and very early in the Devonian the ammonoids evolved from the nautiloids. Both these groups flourished until near the close of the Triassic, when they almost became extinct, only to be revitalized in Jurassic. Throughout the Mesozoic, ammonoids were more numerous than nautiloids. During the Cretaceous, ammonoids were the largest and among the most abundant of the invertebrates and nautiloids were not rare. However, at the end of that period, the former became extinct, and after the early Tertiary the nautiloids dwindled rapidly. Few if any are known from the Pliocene and none from the pre-Recent Pleistocene, though, of course, the ancestors of modern *Nautilus*, a relic, must have been in existence during those times (Miller and Furnish, 1990).

The tetrabranchiate cephalopods are among the very best of our guide or index fossils. The ammonoids in particular are good stratigraphic indices, and the marine strata of the later Paleozoic and Mesozoic are zoned with reference to them (Miller and Furnish, 1990).

Origin of Ammonoidea:

The ammonoids evolved from the nautiloids, but intermediate forms are not known. The only possible exception is the Bactritina, of uncertain affinities. Typically, ammonoids have a tightly coiled thin shell, a bulbous **protoconch**, and a small marginal **siphuncle**. *Bactrites* and its affines possess these characters except for their straight **conchs**. It has long been contended that they gave rise to the ammonoids by becoming coiled. This belief is conjectural. An alternative hypothesis postulates that the ammonoids arose from some Silurian coiled nautiloids of the general type of *Barradeoceras*. The oldest undoubted ammonoids, which are from the Lower Devonian, are reminiscent of certain contemporaneous and slightly older nautiloids. Nevertheless, it may be significant that some of the some of the early Devonian goniatites are loosely coiled, and still others have an **umbilical perforation**. Thus, it appears that there are no preponderant supporting data to establish the identity of the ancestral form (Miller et. al., 1990).

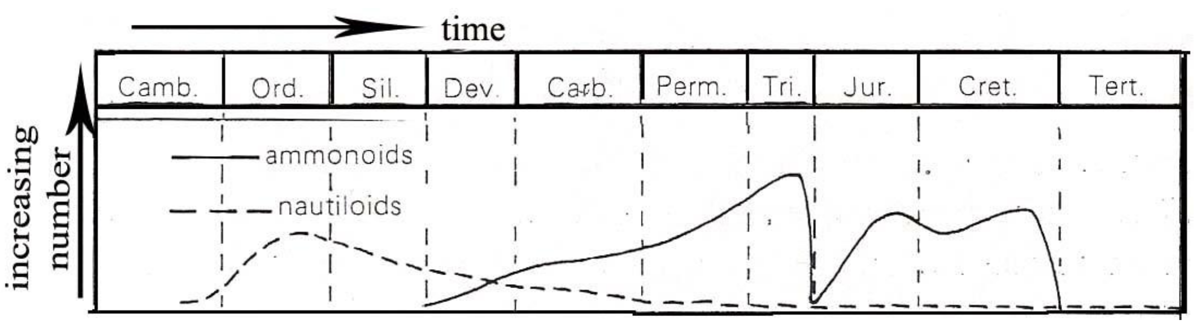


Fig. (1.3): Diagram to show the numerical variation of ammonoids and nautiloids during geological time (Black, 1978).

1.8 Previous work:

a) Stratigraphy:

The stratigraphy of the Upper Cretaceous of Jordan and its subdivisions into groups and formations has become established through the successive works starting in early 1950s (Burdon, 1959; Masri, 1963; and Bender, 1974).

In 1959 **Burdon** had divided the Upper Cretaceous into two groups, Ajlun Group and Belqa Group. The Ajlun Group embraces all the marine sediments of approximately Cenomanian and Turonian age that overly the fluvial Kurnub Group of the early Cretaceous. The Belqa group embraces all sediments laid down in east Jordan from the end of the Turonian to the final emergence of the Tethys in the area in the late Eocene/Oligocene. Then in 1963 **Al Masri** had divided the Ajlun and Belqa groups into formations. Ajlun group comprises the following formations (from older to younger): Na'ur, Fuheis, Hummer, Shueib, and Wadi Es Sir (Cenomanian-Turonian). The Belqa group consists of the following formations (from older to younger): Amman (included the present nomenclature of Ghudran, Amman, and Al-Hisa) and Muwaqqar. In 1974 **Bender** had divided the Upper Cretaceous into seven units according to the lithology, as following:

Chert limestone unit ………………………………. Youngest

Chalk-Marl unit

Phosphorite unit

Silicified limestone unit

Massive limestone unit

Echinoid limestone unit

Nodular limestone unit ……………………………. Oldest

The Nomenclature of Belqa Group will be mention in more detail in the next chapter.

Bender *op cit.* had talk about Cephalopods in two units, *Echinoid limestone* unit and *Phosphorite* unit, which in their uppermost layers frequently contain a Cephalopod horizon.

b) Paleontology:

Ammonites are considered as a large group of Cephalopods and one of the important fossil groups because of their importance in biostratigraphy. Ammonites are globally recognized as index fossils, this mean that specific genera are found only in specific time span, enabling them to be used as dating tools.

Ammonites were reported in the Upper Cretaceous of Jordan by various authors (e.g. Kherfan, 1987; Al-Harithi and Ibrahim, 1992; Nazzal and Mustafa, 1993; Makhlouf et al, 1996 and Moumani, 2005).

In 1987 **Kherfan** had studied the area as part of NRA bulletin series, he constructed a geological map of the area. He reported many fossils as bivalves, gastropods, ammonites, shark teeth, and foraminifera. In 1992 **Al-Harithi and Ibrahim** had studied four

cephalopod species from Maastrichtian of Wadi Usaykhim outcrop section, Al Azraq area in east Jordan. One species is new: *Eutrephoceras azraqensis*. The other three taxa *Sphenodiscuss* cf. *lobatus*, *Libycoceras ismaeli* and *Baculites ovatus*. In 1993 **Nazzal and Mustafa** had studied the Upper Cretaceous Ammonites from north Jordan. They described the genera *Acanthoceras*, *Neolobites*, *Baculites*, *Pseudoshloenbachia*, *Pachydiscus* and *Libycoceras* from the Wadi Shueib, Wadi Es Sir, Wadi Umm Ghudran, Amman and Muwaqqar formations. In 1996 **Makhlouf *et. al*.** had studied the Ajlun group in three sites in Jordan; they found some Ammonites species in two localities. The first locality Ras an naqab section: *aff Metoiceras sp.*, the second locality Wadi ben Hammad section: *Vascoceras aff. Cf. cauvini, aff Schloenbachia spp., aff Tropitiodes sp., Neolobites sp., aff vascoceras spp.* In 2005 **Moumani** had studied Wadi Al Bahiya area, adjacent to the study area (Jibal Ghuzayma), as part of NRA bulletin series, he construct composite columnar section of Muwaqqer Formation, the majority of this columnar section were from Jabal Tuwayyil Shuhaq. He reported macro- and micro-fossils; ammonites, bivalves, gastropods, shark teeth as macrofossil, but he did not mention any classification of the ammonites. He reported that the fault systems are E-W, NE-SW and N-S directed.

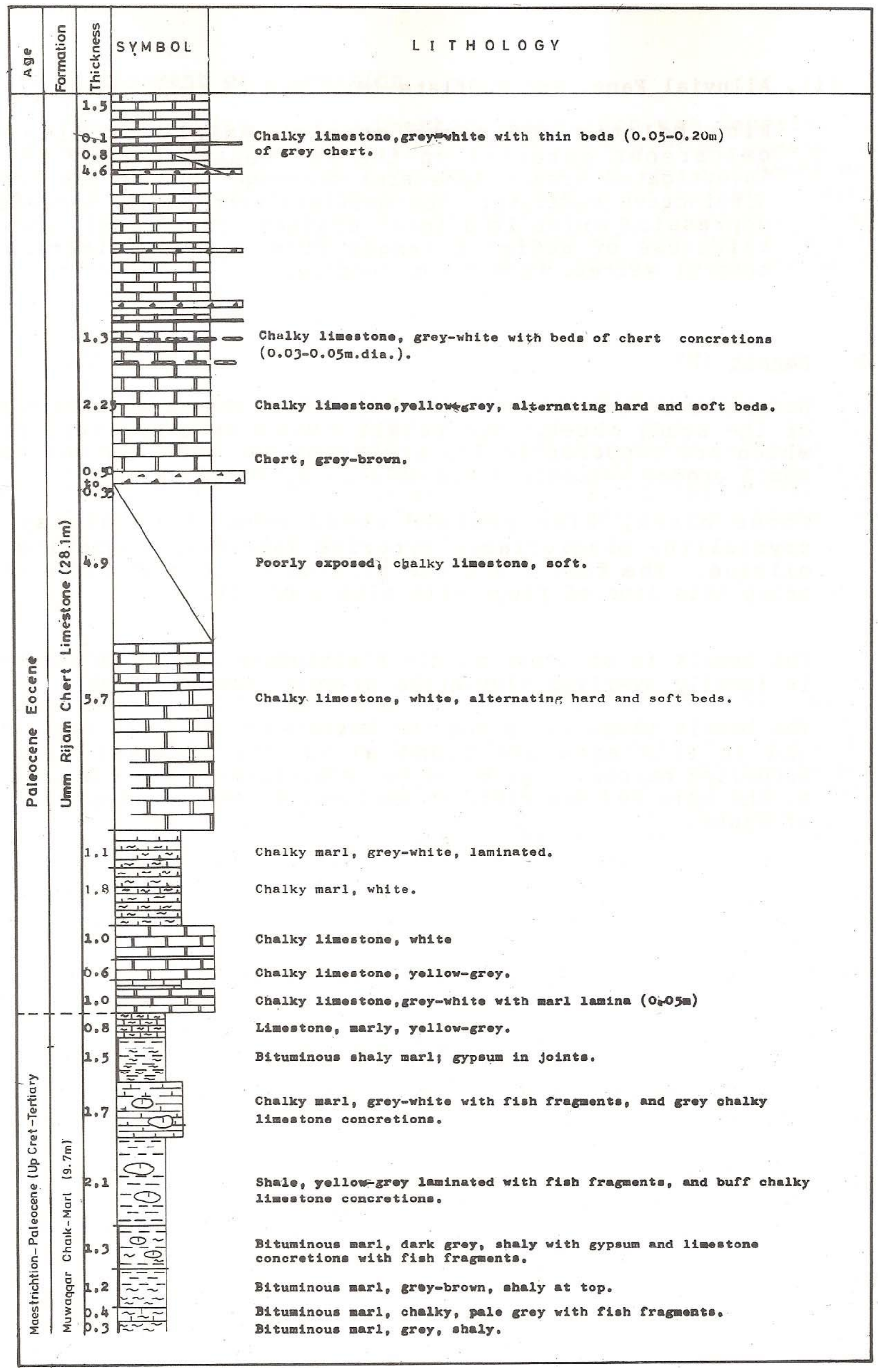


Fig.(1.4): Columnar section of the upper part of the Muwaqqar Formation and lower part of Um Rijam Formation of Jibal Ghuzayma, (map sheet no. 3251-II Kherfan, 1987).

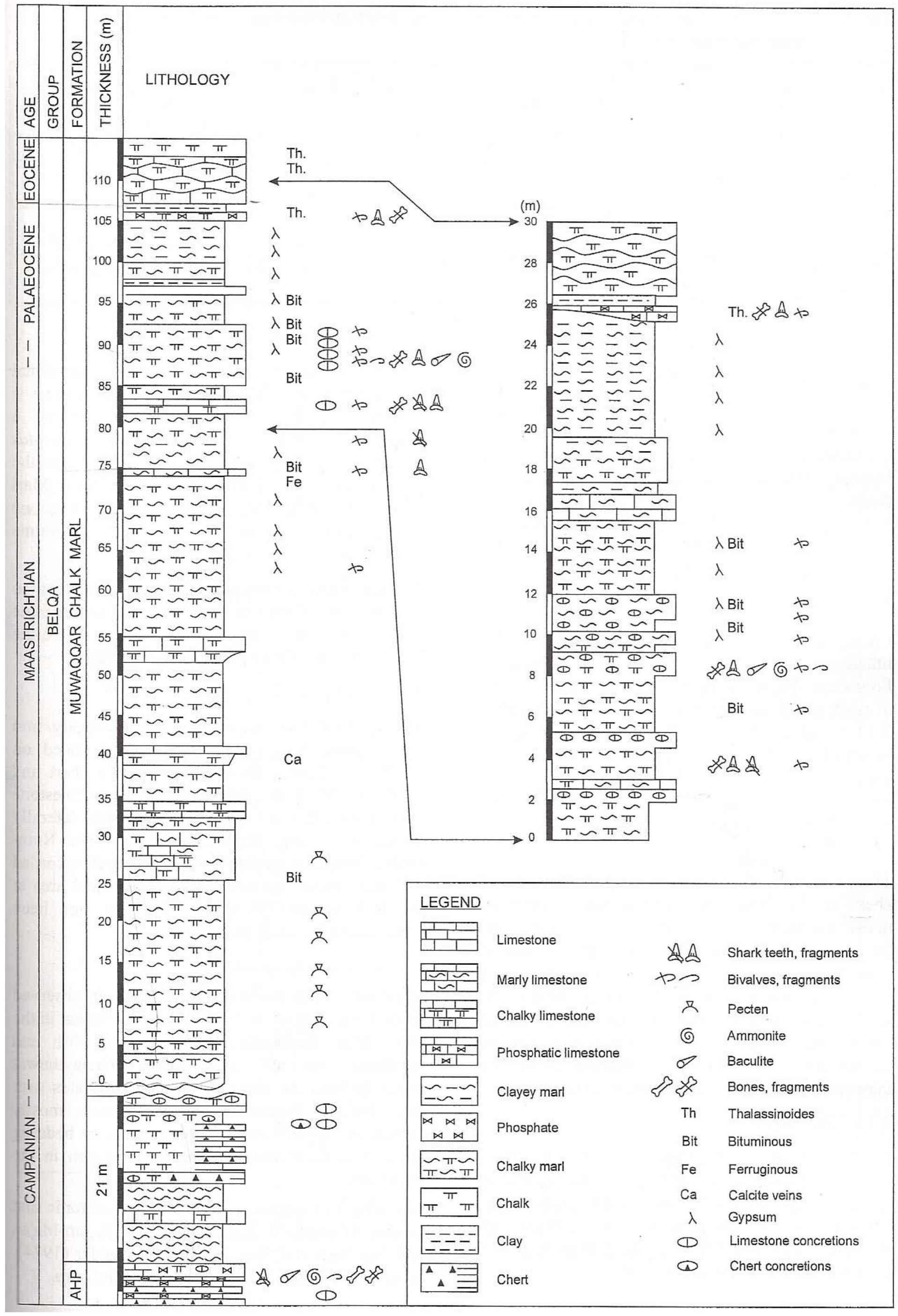


Fig. (1.5): composite graphic log of Muwaqqar Chalk Marl Formation. The formation was measured in Jabal Tuwayyil Shuhaq (30 35 N, 36 08 E) and Wadi Al Bahiya, (map sheet no. 3251-III Moumani, 2005).

Glossary of morphological terms of ammonoid which mention in text:

Camera: compartment between two adjacent septa comprising one of the spaces into which entire shell between protoconch and body chamber is divided by the septa.

Conch: complete shell of ammonoid less the protoconch.

Protoconch: first chamber of shell, closed by pro-septum; sometimes called initial chamber or apical chamber.

Siphuncle: narrow longitudinal tube passing through camera and septa from protoconch to base of body chamber.

Umbilical perforation: vacant space around axis of coiling and connecting umbilici.

1.9 Geological setting

1.9.1 Regional stratigraphy:

The Upper Cretaceous rocks are essentially marine carbonates that cover wide areas of Jordan. They were divided into two groups: older or the Ajlun Group, Cenomanian-Turonian in age, and younger or Belqa Group which extends to the upper Eocene (Burdon, 1959). The two groups were then subdivided into formations by several authors (Table 2.1). The nomenclature of the Natural Resources Authority (National Mapping Project) (Hiyari, 1985) will be used throughout this thesis.

While the study area was covered by the Muwaqqar Chalk Marl and Um Rijam Formations which belong to the Belqa group, this group will be reviewed in detail.

1.9.1.1 Belqa Group

Belqa Group was first coined by Quennell (1951) and Burdon (1959) after the Belqa District around Amman. Several authors subdivided the group into formations and/or units since the early 1960s including Masri (1963), Parker (1970), Bender (1974) and the NRA (Hiayri, 1985) amongst others.

Table 1.1 Nomenclature of the Upper Cretaceous strata:

Age		Group	Formation & member				
			Wolfart (1959) MacDonald (1965)	Masri (1963)	Bender (1974)	Hiari (1985) Powell (1989)	
Tertiary	Eocene	Belqa	B5			Shallala	
	Paleocene		B4		Chert Limestone	Um Rijam Limestone	
Upper Cretaceous			B3	Muwaqqar	Chalk Marl	Muwaqqar Chalk Marl (MCM)	
	Maastrichtian		B2 B2b	Amman	Phosphorite	Al Hisa Phosphorite (APH)	Qatrana Bahiyah Sultani
	Campanian		B2 B2a		Silicified Limestone	Amman Silicified Limestone (ASL)	Mutarammil Coquina
	Santonian		B1		Massive Limestone	Um Ghudran Chalk	Dhiban Chalk Tafila Mujib Chalk
	Coniacian						
	Turonian	Ajlun	A7	Wadi Es Sir		Wadi Es Sir	
			A5-6	Shueib	Echinoid Limestone	Shueib	
	Cenomanian		A4	Hummar		Hummar	
			A3	Fuheis	Nodular Limestone	Fuheis	
			A1-2	Na'ur		Na'ur	
Lower Cretaceous		Kurnub					

The Belqa Group embraces all sediments laid down in east Jordan from the end of the Turonian to the final emergence in the Oligocene as defined by Quennell (1951). Therefore, they commence when the sea was transgressing farther inland towards the south-east and end when these seas had finally retreated (Burdon, 1959). Belqa Group includes the top of the Upper Cretaceous and the Tertiary sediments, so the Cretaceous-Tertiary (Mesozoic-Cenozoic) boundary exists in this group (Abed, 2000).

The Belqa Group is comprised of many lithofacies such as chalk, chert, phosphate, oil shale, limestone, marl and sandstone. It covers a large area of Jordan, but it outcrops only on a small scale in the western mountains of Jordan because of the uplifting of the area due to the uplift associated with the Rift Valley and the removal of the group by erosion. The group crops out extensively east of the western mountains and extends to cover the rest of middle, northeast, and southeast of Jordan.

The group begins with thick chalk level from Wadi Um Ghudran Formation, forming the lower boundary of the group which is very clear because it refers to a regional disconformity and a transition from shallow subtidal marine environment at the end of Ajlun Group to clear marine transgression in Ghudran chalk over most of Jordan except the remote south. There is no need for the upper boundary of the group because there are no marine sediments above it, due to the entire regression of the Tethys from the area (Abed, 2000). The Belqa Group is around 650 m thick in northern Jordan gradually thinning towards the south and southeast (Powell, 1989).

The Belqa Group ranges in age from the Coniacian to Eocene. (Bender, 1974; Powell, 1989; Abed, 2000) and comprises the following formations from bottom to top: Wadi Um

Ghudran Chalk, Amman Silicified Limestone, Al Hisa Phosphorite, Muwaqqar Chalk Marl, Um Rijam Chert Limestone, and Shallala. Following is a short description of these formations. See also Table 1.1.

1.9.1.1.1 Wadi Um Ghudran Chalk Formation:

The name is taken from Wadi Um Ghudran Ed Dib, southeast of Irbid, where the type section was described by Macdonald (1965 a and b) who called it the Ruseifa Formation. Parker (1970) proposed the present name which is equivalent to the B1 of Wolfart (1959). The formation was included in the Amman Formation by Masri (1963).

It is probably equivalent to the upper part of Massive Limestone Unit or Sandy Limestone Units of Bender (1974). The National 1:50.000 Mapping Project follows Parker's nomenclature and subdivided the formation into three members from bottom to top: Mujib, Tafila, Dhiban, and Alia members (Moumani, 2002; Masri 2003).

The Ghudran Formation is characterized by significant lateral changes from north Jordan through the middle, south, and southeast parts of the country where the thickness and description of the formation change dramatically. In north Jordan until Madaba, Ghudran Formation consists of one type of lithology, massive chalk ranging in thickness from 20 to 35 m. In central Jordan, the formation becomes relatively thick, and it was divided into three members;

<u>Mujib Chalk (lower member)</u>: consists of white massive chalk, in addition to transported material from oyster shells, fish teeth, and phosphate granules. This member ends with the appearance of thick massive layer of certified coquina, (Abed, 2000).

<u>Tafila Member (middle member)</u>: it is characterized by bedded chert, relatively thick and is composed of two rock units. The lower unit is a mixed mineralogy, composed of a number of rocks, including chert, cross-laminated dolomite, and brecciated chert. The second unit is the porcellanite (Tripoli) unit, which consists of porcellanite, chert and dolomite (Abed, 2000).

<u>Dhiban Chalk (upper member)</u>: consists of white chalk, sometimes reddish massive chalk and contain transported oyster shells (fossilized) (Abed, 2000).

In south Jordan, the Ghudran Formation contains layers of tripoli and sandstones, Tarawneh (1988) and Powell (1988 and 1989b) called this unit Alia Member.

Parker (1970) assigned the formation a Santonian age, whereas Powell (1989b) indicated a possible late Coniacian- Campanian age range (Moumani, 1997).

Generally the Mujib and Dhiban Chalk members are pelagic deep marine deposits, whereas the Tafila Member was probably deposited in a shallow marine environment with offshore banks forming the sand facies in the south (Powell, 1989). Large-scale, flat based cross-stratified sand banks indicate a moderate water depth, where sand was reworked by storms

and waves into offshore banks (Powell, 1989). The presence of tripoli and tripolized chert indicates shallow environment and change in the sea chemistry (Moumani, 1997).

1.9.1.1.2 Amman Silicified Limestone Formation:

The name is taken from the capital Amman, where it forms a large part of the exposed bedrock. This rock unit has been called the Amman Formation of Masri (1963) and the Silicified Limestone Unit (Bender, 1968 and 1974). It is equivalent to the middle cherty horizon of the Calcaires de Silex de Qatrana (Wetzel and Morton, 1959), the lower B2 of Wolfart (1959), the lower part (B2a) of the B2 (MacDonald, 1965a and b), (Masri, 2003).

Amman Silicified Limestone Formation forms a prominent scarp feature. The predominant lithology of hard chert produces a distinctive well bedded feature above the soft massive chalk of the underlying Wadi Umm Ghudran Formation (Tarawneh, 2007).

The formation consists of, thin to thick bedded heterogeneous lithology, grey, white or brown chert exhibiting a variety of textures ranging from homogeneous to brecciated, grey microcrystalline limestone (beds and concretions), dolomitic chalky marl and thin chalk beds. The principal lithological types described below and the petrographic details are present in Powell (1989b) and Abed and Kraishan (1993);

i) Chert is present as three lithotypes: concretionary dense chert, homogeneous pinch and swell chert and brecciated chert. The concretionary dense chert is

composed of alternating bands of microquartz with thin chalcedony bands. The homogeneous chert of brown, grey, black and white colour consists of micro- and cryptocrystalline quartz with length fast chalcedony silica in veins. Pinch and swell beds commonly interbedded with chalk marl or microcrystalline limestone (micrite). Brecciated chert has been termed autobrecciated to distinguish it from tectonically brecciated chert (Powell, 1988). The fossils replaced by silica suggest early diagenetic silicification (Abed and Kraishan, 1993; Masri, 2003).

ii) Microcrystalline limestone occurs as beds and concretions, and consists of micrite and/or wackestone with cerithide gastropods or small bivalves. Occasionally the tops of the beds have granular phosphate-filled *Thalassinoides* burrows; macro-fossils are also concentrated on the upper bedding surface (Masri, 2003).

iii) Chalk and marl are finely laminated and interbedded with chert and limestone. These are white to pink-tan in colour, and locally contain coarse dolomitized infill in *Thalassinoides* burrows (Masri, 2003).

iv) Oyster coquinal grainstones consists of fragmented shells and grainstone with large-scale trouph cross bedding. This texture and sedimentary structure indicate strong waves (Masri, 2003).

v) Phosphate occurs as granules (fish and reptile skeletal fragments) and more rarely as pelloids (Masri, 2003).

Based on the foraminifera content (Harithi, 1982) assigned the Amman Silicified Limestone Formation in Wadi Al Mujib area to be Santonian to Campanian in age.

However, Wetzel and Morton (1959) and Basha and Mikbel (1987) in Irbid and Edh Dhira areas respectively, proved only the presence of Campanian age (Masri, 2003).

The presence of diverse benthic fauna and oyster-rich coquina suggests a shallow to deep water subtidal marine environment. The Mutarammil coquina was deposited in shallow marine water. The increase in the proportion of granular cherty phosphate and thin coquinal shelly limestone (wackestone texture) near the top of the formation indicates a gradual upward shallowing with a passage into the overlying Al-Hisa Phosphorite Formation (Powell, 1989). Futyan (1968) suggests that the formation was deposited in a transgressive sea.

1.9.1.1.3 Al-Hisa Phosphorite Formation:

Al-Hisa Phosphorite Formation is named after Al-Hisa city in Central Jordan (Hiyari, 1985). Blanckenhorn (1903) was the first to describe phosphate in Jordan, 16 km northwest of Amman. The formation is equivalent to the upper part of Calcaires Silex (Wetzel and Morton, 1959), B2 of Wolfart (1959), the upper part of Amman Formation (Masri, 1963), the upper part (B2b) of B2 Silicified Limestone and Phosphorite Formation (MacDonald *et. al.*, 1965), the upper part of the Amman Formation of Parker (1970), and the Phosphorite member of Bender (1974) (Moumani, 2005 and 2006).

Al-Hisa Formation consists of diverse lithologies including phosphate, cherty phosphate, phosphatic limestone, chert, microcrystalline limestone, cross-bedded oyster coquina and bituminous marl. The formation has been subdivided into three members; in ascending

order these are; Sultani Phosphorite, Bahyia Coquina and Qatrana Phosphorite (Hiyari, 1985; Barjous 1986; Khalil, 1986).

*i)*Sultani Phosphorite Member: it consists mainly of phosphate, cherty phosphate, phosphatic limestone, limestone, bituminous marl and fragmentary oyster coquina (Moumani, 2005).

ii) Bahiya Coquina Member: It is characterized by large cross-bedded banks resulting in rapid lateral changes in thickness. It consists of well preserved oyster rich shelly limestone with noticeable size gradation (Moumani, 2005).

iii) Qatrana Phosphorite Member: consists of phosphate, limestone, cherty coquinal, limestone, phosphatic limestone, cherty phosphate, marl and marly limestone. Phosphate beds are present in two types; grey friable phosphate including concretions of limestone and grey hard granular phosphate consists of pelloids, shark teeth, fish fragments and siliceous bones. White-grey and pink limestone present as beds and concretions is mainly micritic and to less extent phosphatic. The thickness of this member is affected by palaeomorphology of the underlying Bahiya Coquina (Moumani, 2005).

Al-Hisa Phosphorite Formation was assigned a Campanian age by Wetzel and Morton (1959), and Campanian-Maastrichtian by Bender (1974). The presence of 16 species and sub-species of Globo-truncana in the upper part of al-Hisa Phosphorite Formation in Dier Abu Said area indicates an early to middle Maastrichtian age (Mikbel and Abed, 1985;

Hamam, 1987). The reported *Libycoceras sp.* and *Analinoceras relexum* ammonites in the upper part of the equivalent formation west of the rift indicates late Campanian age (Reiss et al., 1985) (Moumani, 2005).

The presence of benthic biota, burrows, sedimentary structures including cross-bedding indicate that the formation was deposited in shallow marine subtidal to intertidal environment. The Bahiya Coquina was deposited in shallow water possibly intertidal environment. Shallowing is indicated by the presence of massive large scale cross-bedded oyster banks (Moumani, 2005).

1.9.1.1.4 Muwaqqar Chalk Marl formation:

The Muwaqqar Chalk Marl Formation defined here is named after Muwaqqar area 35 km southeast of Amman, and was first used by Masri (1963). The formation is equivalent to Chalk Marl (B3) unit (Wolfart 1959; MacDonald and Partner (1965), Muwaqqar Formation (Parker, 1970) and Chalk Marl Unit of Bender (1974), (Moumani, 2005).

The Muwaqqar Chalk Marl Formation is made up of predominantly soft pale yellow, light grey, yellowish to reddish and brownish green, occasionally whitish cream chalky marl and marly limestone with primary and secondary gypsum occurs as thin bands or together with calcite in extensional joints. The formation includes dark grey green bituminous marl and marly limestone (Moumani, 2005).

The formation is unexposed in the western mountains because of the uplifting of the area due to the uplift associated with the Dead Sea Rift Valley, the formation cropsout

extensively in the eastern mountains and covers a large area of Jordan Plateau (Abed, 2000).

The thicknesses of this formation were influenced by the paleotopography of the continental shelf of Tethys Ocean; it is thicker in basins than in highlands (Abed, 2000). Here are the thicknesses in some areas in Jordan; in Yarmuk 332 m, Irbid 240 m, east of Lisan 158 m, Gharandal 94 m, Al-lajun 115 m and Ras Al-naqab 20 m (Powell, 1989) and 110 m Jabal Tuwayyil Shuhaq (Moumani, 2005).

1.9.1.1.5 Umm Rijam Chert Limestone Formation:

The formation is named after Jabal Umm Rijam in south central Jordan east of Jurf Ed Darawish, where Heimbach et al. (1962) and Parker (1970) proposed the type section. The formation is equivalent to the Calcaires Crayeu a silex de Sar'a (Wetzel and Morton, 1959), variable Eocene limestone (8f) unit of Burdon (1959), the chalk and chert (B4) of Wolfart (1959), B4 chert and limestone unit (MacDonald and Partner, 1965), the Rijam Formation (Parker, 1970) and Chert Limestone Unit of Bender (1974) (Moumani, 2005).

Chalk, chert and limestone are the predominant lithologies of Umm Rijam Chert Limestone Formation. The formation can be subdivided informally into three lithostratigraphic members easily traced in aerial photographs; lower chalk, middle chert and chalk, and the upper part is predominantly limestone alternating with chalk and chert lenses (Moumani, 2005).

Micropalaeontological studies indicate that the age of this formation in Central Jordan is Palaeocene-Eocene (Koch, in Bender, 1974). The presence of Nummulites in Ma'an and Gharandal areas suggests Middle Eocene age (Wetzel and Morton, 1959) (Moumani, 2005).

Chalk, chert and limestone are volumetrically the main lithologies of Umm Rijam Chert Limestone Formation. The absence of benthic macrofauna, and the presence of planktonic and benthic foraminefra in addition to the predominance of calcareous nano-plankton, and uniform lithologies which developed over a wide area, suggest a deep water pelagic environment (Powell, 1989b), (Moumani, 2005).

1.9.1.1.6 Shallala Formation:

The Shallala Formation defined here is named after wadi Shallala north Irbid by Parker (1970). The Shallala Formation consists of chalky limestone, marly limestone, marl, chalk marl and nummulite bioherm. This formation was the last formation deposited from Tethys Ocean, because the regression of Tethys (Upper Eocene) (Abed, 2000).

The formation crops out in few locations in Jordan, such as Wadi Shallala, Wadi Gharandal and Wadi Araba. The thickness of Shallala Formation is 70 m in Wadi Shallala, the age is Middle to Upper Eocene (Abed, 2000).

1.9.2 Regional structure of the study area:

The study area is crossed by NNW - SSE, Al Karak – Al Fayha fault system (Kherfan, 1987), Al Karak – Al Fayha fault is part of the transverse fault system, the age of this system is Miocene to Pliocene, (Abed, 2000).

Al Karak – Al Fayha fault system is crossing Jordan from the Dead Sea and passing to the southeast beyond the Saudi border; more than 300 km in length, (Moumani, 2006).

The maximum vertical displacement on the fault segments is 50 m, (Bender, 1974).

The fault system is bounded by flexures and extensional (normal) faults, which form grabens, that narrow towards the northwest. Adjacent to the Dead Sea Rift, it is represented by a series of small fault with diminishing throw when trend WNW-ESE. As the main fault zone is traced to the northwest along the flanks of Wadi Karak it is mostly obscured by landslides. There is no evidence on lateral movement on this fault system, (Moumani, 2008).

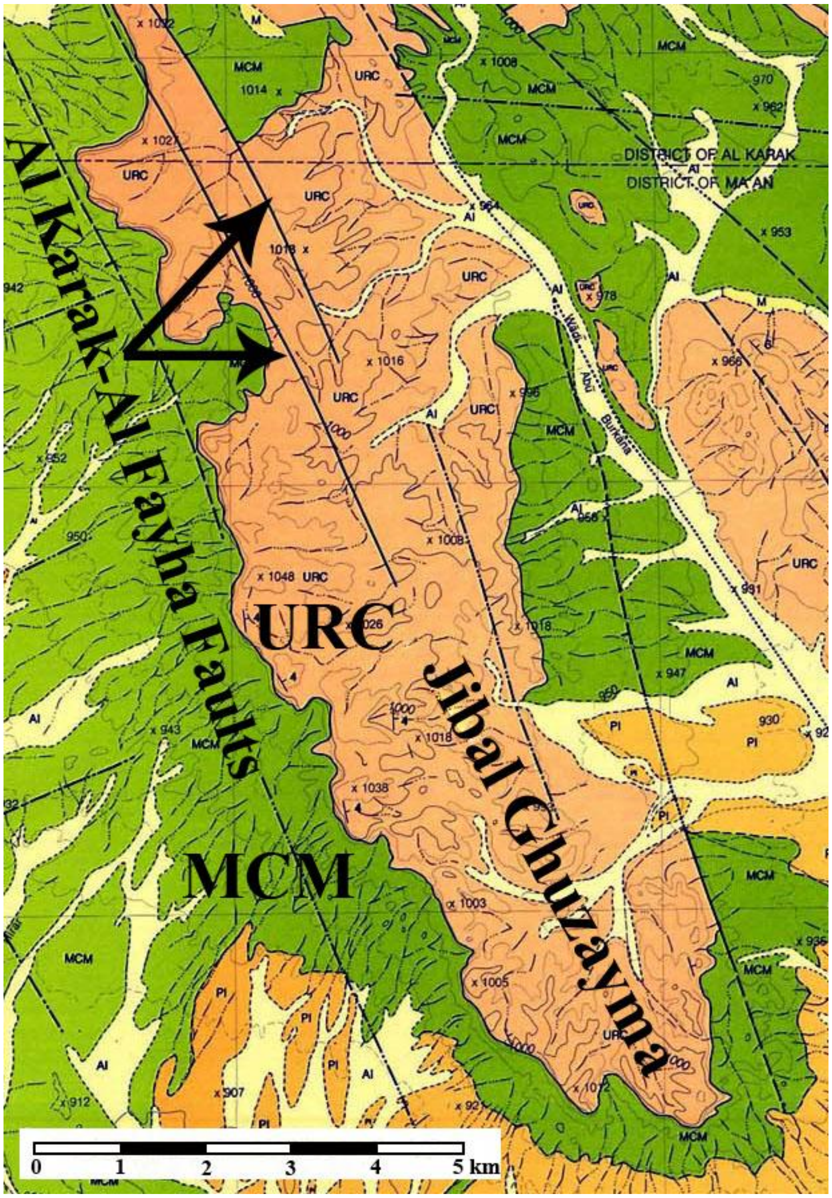


Fig. (1.6): part of the geological map of Jibal Ghuzayma (map sheet No. 3251 II) shows the faults in the study area (NNW – SSE), Al Karak – Al Fayha fault, (URC: Um Rijam Chert Limestone Formation, MCM: Muwaqqar Chalk Marl Formation, scale in km's) (Kherfan, 1987).

Chapter Two

Stratigraphy of the study area

Muwaqqar Chalk Marl (MCM) Formation has a broad distribution and covers the majority of the study area. The base of this formation is unexposed; it is overlain by Um Rijam Chert Limestone Formation.

A location was selected to measure a columnar section of the MCM and to collect samples, the total thickness of the section in this location is 33 m (Muwaqqer Formation 28.6m and Um Rijam Formation 4.4m), which is divided into 10 units with 6 concretion levels, and 12 samples were collected from these units to use in microfacies analysis.

The first nine units belong to upper part of Muwaqqar Formation; the final unit belongs to Um Rijam Formation.

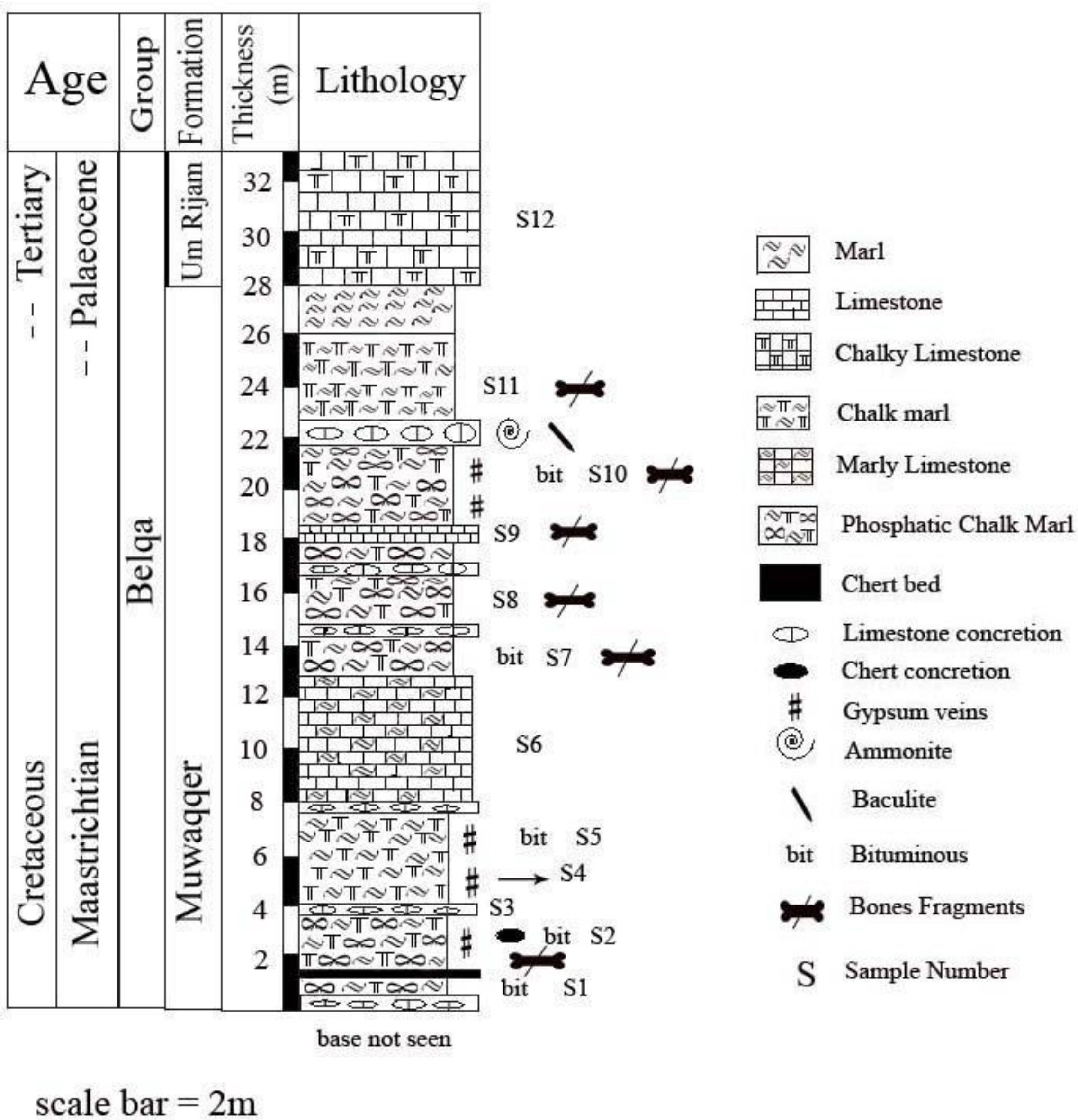


Fig. (2.1): columnar section of the study area (Jibal Ghuzayma (30 33 N, 36 20 E)) of Muwaqqar Formation and Um Rijam Formation.

Muwaqqar Formation:

Unit one: 4 m of laminated friable, brownish phosphatic bituminous chalk marl, contain bones fragments, two concretion levels (hard, light brown limestone and contain many fossil fragments) and contain chert bed (Figure 2.1& 2.2) (Sample 1-3)



Fig. (2.2): unit one of the section and the concretion level two.

Unit two: 4 m of laminated, moderately hard, bituminous chalk marl, contain concretion level at the top, contain fossil fragments (bivalve and others) and secondary gypsum veins (Figure 2.1 and 2.3) (Sample 4&5)

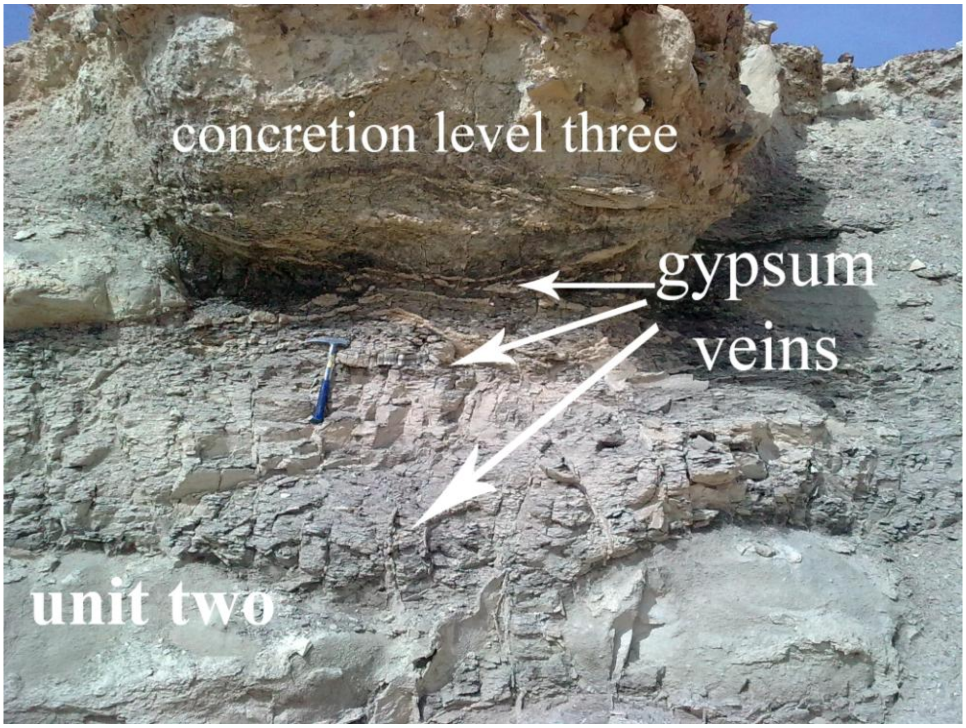


Fig. (2.3): unit two with the secondary gypsum veins (vertical and horizontal) and concretion level three.

<u>Unit three</u>: 4.5 m of moderately hard, yellowish marly limestone with little amount of fossil fragments (Figure 2.1) (Sample 6).

<u>Unit four</u>: 2 m of friable, grayish phosphatic bituminous chalk marl, contain bones fragments (Figure 2.1) (Sample 7).

<u>Unit five</u>: 3.5 m of laminated, friable, brownish bituminous phosphatic chalk marl with bones fragments and contain two concretion levels (Figure 2.1) (Sample 8).

<u>Unit six</u>: 60 cm of very hard, creamy limestone with bones fragments (Figure 2.1) (Sample 9).

Unit seven: 4 m of laminated (flakes), greyish bituminous phosphatic chalk marl contains a lot of bones fragments (Sample 10). The concretion level that includes the ammonoids and baculites exists at the top of this layer (Figure 2.1 and 2.4)

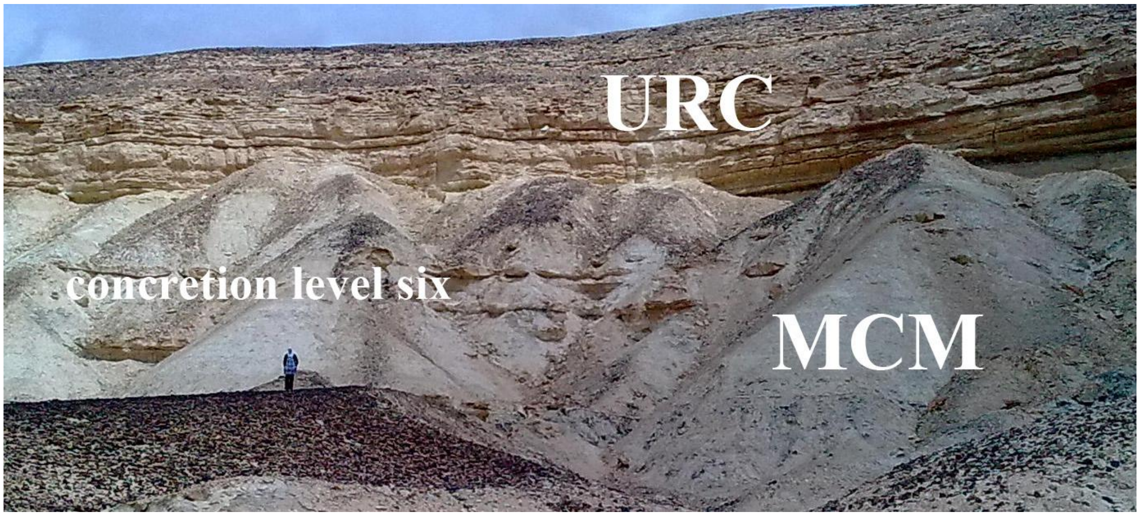


Fig. (2.4): Um Rijam Formation (URC), Muwaqqar Formation (MCM) and concretion level six that includes the ammonoids and baculites.

Unit eight: 4 m of laminated, light brown chalk marl with bones fragments (Figure 2.1) (Sample JG 11)

Unit nine: 2 m of friable, yellowish marl (Figure 2.1)

Um Rijam:

Unit ten: 4.4 m from the lower part of Um Rijam Formation, very hard, yellowish chalky limestone (Figure 2.1) (Sample JG 12).

Chapter Three

Systematic paleontology

This chapter includes the systematic classification with a description of the recorded Ammonite species. Description of the Ammonite specimens will take the following scheme assessing on the preserved morphological characters. Among these characters, those most frequently used are the suture line, shell coiling, whorle cross section and shell ornamentation.

49 samples of ammonite were collected from the study area during the field work; they were classified into three species:

3.1) Phylum Mollusca

Class Cephalopoda Leach, 1817

Order Ammonoidea Zittel, 1884

Suborder Ammonitina Hyatt, 1889

Superfamily Acanthocerataceae Hyatt, 1900

Family Sphenodiscidae Hyatt, 1900

***Sphenodiscus* Meek, 1871**

Figure (3.1)

Type species: *Ammonites lenticularis* Owen, 1852 (non Phillips, 1825)

[=*Ammonites lobatus* Tuomy, 1856].

Sphenodiscus lobatus (Tuomy, 1856).

Material: One well preserved external shell and four well preserved internal moulds (three entire samples and two fragmented) found in the final concretion level.

Description: The specimens are involute. The whorle section is triangular; the ventral side is thinner than the umbilicus. The whorl height is greater than the whorl width. The shell is smooth (there is no ornamentation). The suture line is well preserved (belongs to pseudoceratites suture), the saddles are entire and elongated and the lobes are highly teethed. The saddles and lobes tend to become smaller from the venter toward the umbilicus.

Table 3.1: Dimensions of *Sphenodiscus lobatus*:

Sample no.	Diameter (mm)	Whorle Height (mm)	Whorle Width (mm)
1	105	55	?
2	150	45	40
3	195	80	50

Distribution: the specimens were collected from the wadi but their source from the upper most concretion level from Muwaqqar Formation (see figure 2.1).

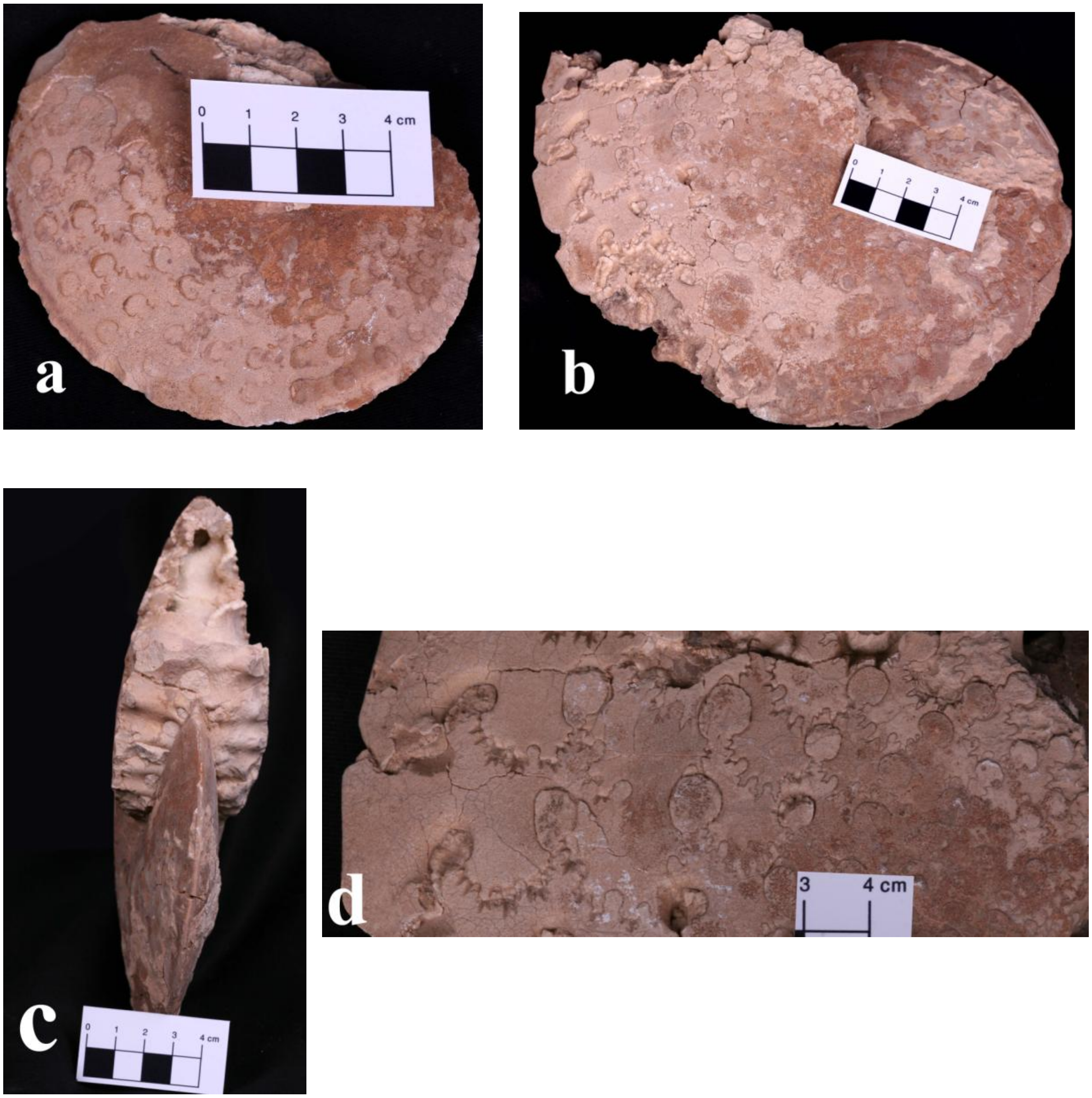


Fig (3.1): *Sphenodiscus* Ammonites from Jibal Ghuzayma. a: *Sphenodiscus lobatus* (Tuomy, 1856) lateral view.b: *Sphenodiscus lobatus* (Tuomy, 1856) lateral view, c- *Sphenodiscus lobatus* (Tuomy, 1856) ventral view. d- *Sphenodiscus lobatus* (Tuomy, 1856) close view to show the suture line.

3.2) Phylum Mollusca

Class Cephalopoda Leach, 1817

Order Ammonoidea Zittel, 1884

Suborder Ammonitina Hyatt, 1889

Superfamily Acanthocerataceae Hyatt, 1900

Family Sphenodiscidae Hyatt, 1900

***Libycoceras* Hyatt, 1900**

Figure (3.2) and (3.3)

Type species: *Engonoceras ismaeli* Zittel, 1895.

Libycoceras ismaeli (Zittel, 1895)

Material: two samples with external shell and 6 well preserved internal moulds (three entire samples and five fragmented)

Description: the specimens are involute. The whorle section is triangular, the ventral side is thinner than the umbilicus. The whorl height is greater than the whorl width. The shell is smooth (there is no ornamentation) the suture line is well preserved (belongs to pseudoceratites suture, the saddles are entire and rounded and lobes are highly teethed. The saddles and lobes tend to become smaller from the venter toward the umbilicus.

Table 3.2: Dimensions of *Libycoceras ismaeli*:

Sample no.	Diameter (mm)	Whorle height (mm)	Whorle width (mm)
1	140	50	35
2	145	60	40
3	155	60	?
4	140	50	30

Distribution: the specimens were collected from the wadi but their source from the upper most concretion level from Muwaqqar Formation (see figure 2.1).

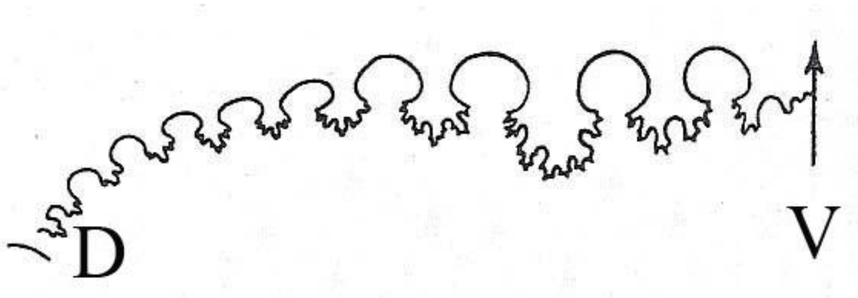


Fig.(3.2): suture line of *Libycoceras ismaeli* (Zittel, 1895) (the suture line become smaller from the ventral (V) to the dorsal (D))

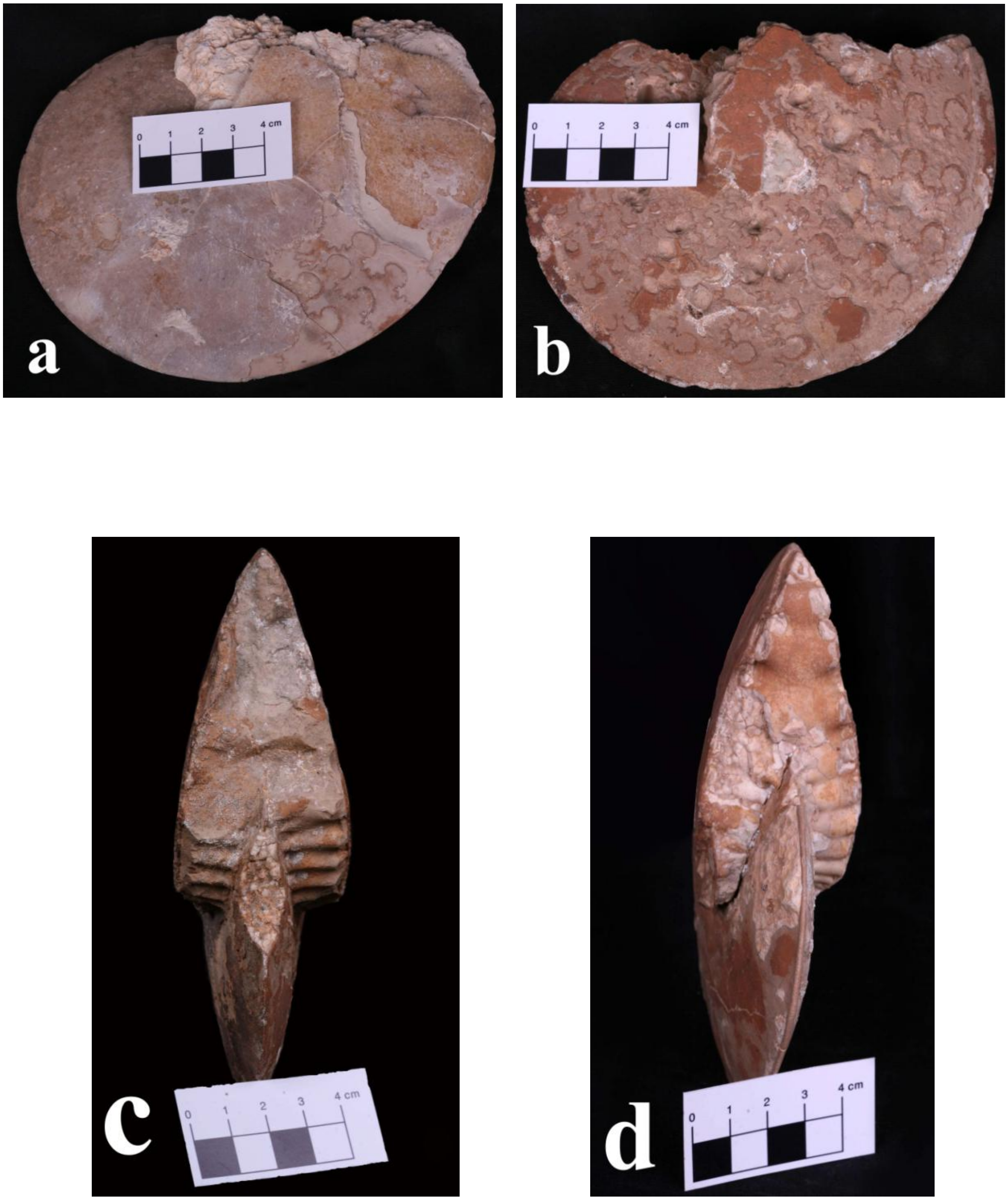


Fig (3.3): Libycoceras Ammonites from Jibal Ghuzayma. a&b: *Libycoceras ismaeli* (Zittel, 1895) lateral view. c&d: *Libycoceras ismaeli* (Zittel, 1895) ventral view.

The two species belong to the same family and have the same morphological character, but the only different between these species is the suture line, both are belong to pseudoceratites suture but *Libycoceras ismaeli* (Zittel, 1895) has entired and rounded saddles, *Sphenodiscus lobatus* (Tuomy, 1856) has entired and elongated saddles with long narrow necks.

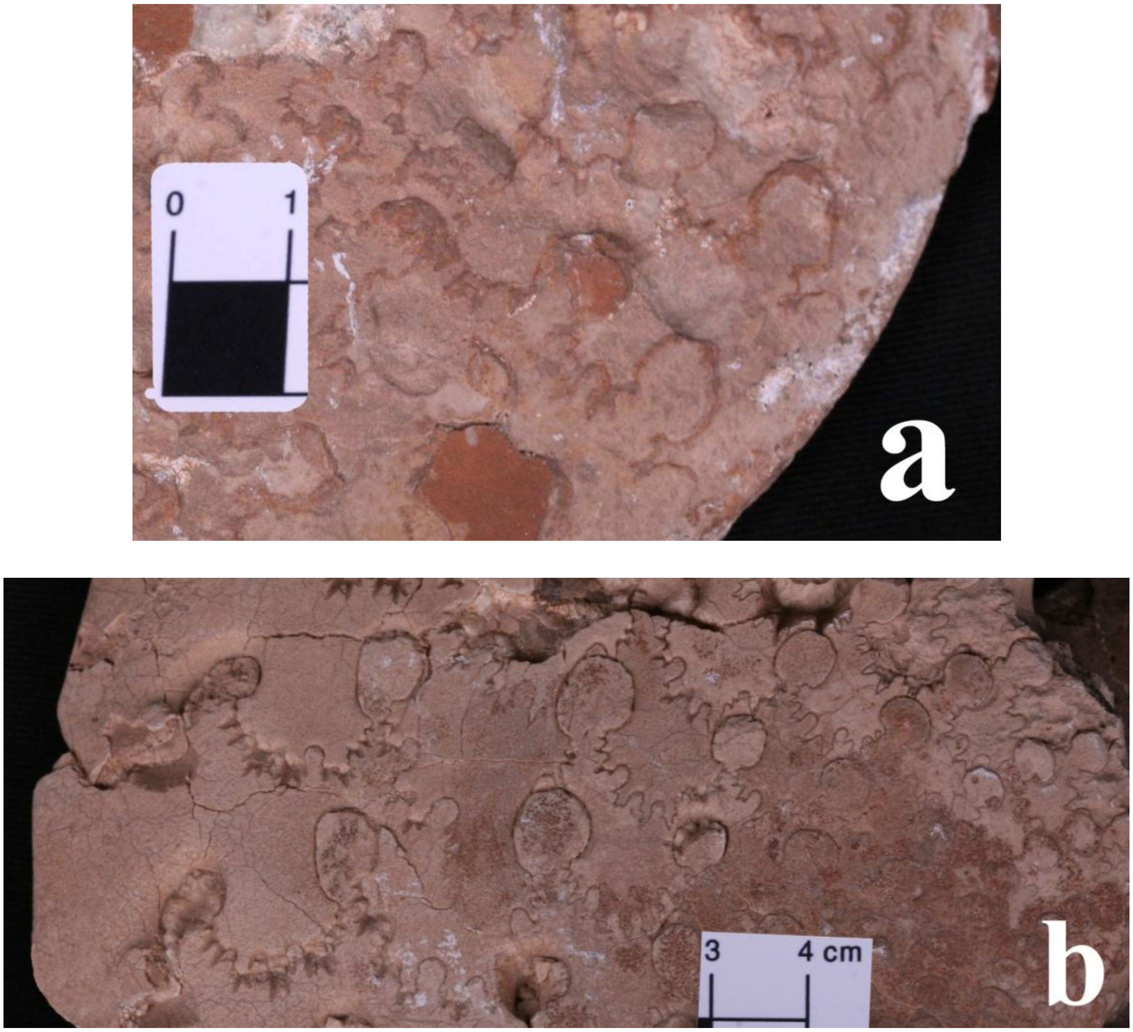


Fig.(3.4): comparing between the suture line of the two species of Sphenodiscidae family. a- suture line of *Libycoceras ismaeli* (Zittel, 1895), b- suture line of *Sphenodiscus lobatus* (Tuomy, 1856)

Sphenodiscidae ammonites were widespread during the Maastrichtian, with records from localities in Africa, Europe and both Americas. Outside North America, however, their record is rather scattered. The genus is known from Maastrichtian sediments in Western Europe, in the lower Maastrichtian of India and in the upper Maastrichtian of Poland and Bulgaria, Madagascar and West Africa. The most widespread species of *Sphenodiscus* is, however *Sphenodiscus lobatus*. Zaborski (1982) suggested that the Sphenodiscidae originated in the African epicontinental seas from unknown ancestor of Campanian age. Sphenodiscids dispersed and radiated during the latest Campanian and Maastrichtian, until they went extinct at or near the Cretaceous-Paleogene boundary (Ifrim and Stinnesbeck, 2010).

Libycoceras ismaeli (Zittel) has been reported from the upper Maastrichtian of the Algerian Sahara, North Africa and Niger, and it has been reported from the upper Campanian in Middle East and Eastern desert, Egypt (Amard, 1996).

The two species were recorded in Jordan in Wadi Usaykhim, Al Azraq area as Maastrichtian age (Al-Harithi and Ibrahim, 1992).

3.3) Phylum Mollusca

Class Cephalopoda Leach, 1817

Order Ammonoidea Zittel, 1884

Suborder Lytoceratina Hyatt, 1889

Superfamily Turrilitaceae Meek, 1876

Family Baculitidae Meek, 1876

***Baculites* (**Lamark, 1799)

Fig. (3.5)

Type species: [*Baculites vertebralis* De France, 1830; SD Meek, 1876] [= *Homaloceras* Hubsch, 1786 (non. binom.)].

Baculites sp. Lamark, 1799

Material: two large and thirteen small, incomplete samples.

Description: the specimen is a part of phragmocone. The cross section is ovate, smooth surface some samples have arcuate ribs. The suture line is moderately complex (belongs to ammonitic suture), the saddles and lobes are teethed.

Distribution: some specimens were collected from the wadi but their source from the upper most concretion level from Muwaqqer formation. Some specimens were found inside the concretions.

Baculites were recorded from Egypt, Mexico, Palestine and North America, it indicates Campanian-Maastrichtian age (Ifrim *et. al.*, 2010). They were recorded in Jordan in Wadi Usaykhim, Al Azraq area as of Maastrichtian age (Al-Harithi and Ibrahim, 1992).

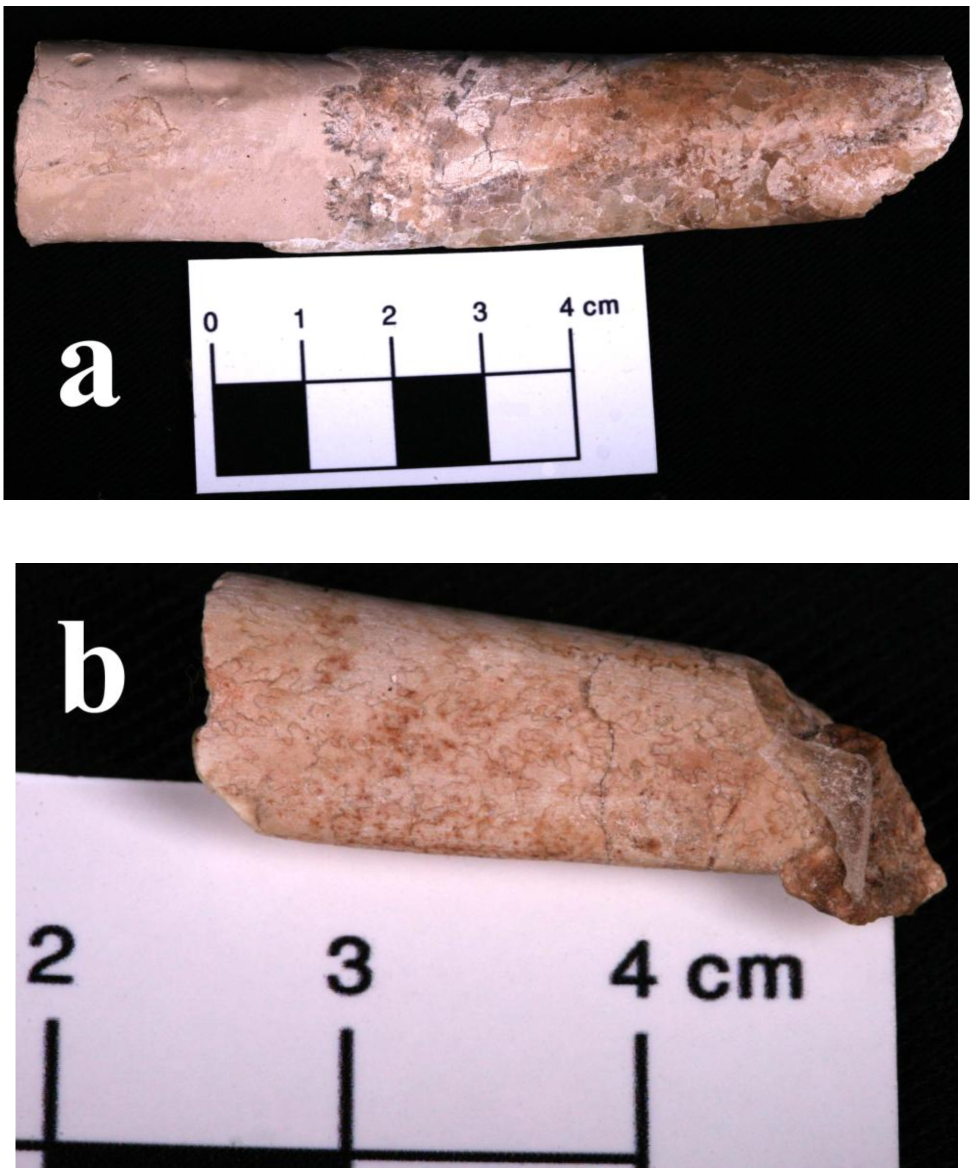


Fig. (3.5): a&b: *Baculites* sp. from Jibal Ghuzayma, different samples.

Table 3.3: the Ammonite species which were found in the study area (Jibal Ghuzayma) and their distributions and ages in different localities.

Ammonite species	**Distribution**	**Age**
Sphenodiscus lobatus	Africa, Europe, both Americas and Jordan. Poland, Bulgaria, Madagascar and West Africa. India and Mexico. Palestine and Nigeria.	Maastrichtian Upper Maastrichtian Lower Maastrichtian Campanian-Maastrichtian
Libycoceras ismaeli	Africa, Europe, both Americas, Nigeria, Libya and Jordan. Poland, Bulgaria, Madagascar and West Africa. Middle East and Eastern desert,Egypt.	Maastrichtian Upper Maastrichtian Upper Campanian
Baculites sp.	Jordan. Egypt, Mexico, Palestine and North America	Maastrichtian Campanian-Maastrichtian

Chapter four

Microfacies Study

The term microfacies was defined originally by Brown 1943. Microfacies is the total of all sedimentological and paleontological data which can be described and classified from thin sections, peels, polished slabs or rock samples (Flügel, 2004). A facies is a body of rock with specified characteristics. In case of sedimentary rocks, it is defined on the basis of colour, bedding, composition, texture, fossils and sedimentary structures (Reading, 1979).

In this study, microfacies analysis of the upper part of Muwaqqar Formation in Jibal Ghuzayma has been carried out. Microfacies nomenclatures followed Dunham's classification (1962) and supported by Folk's classification (1962).

The facies in general, are composed mainly of four constituents (micrite, foraminifera, phosphate particles and calcite cement (sparite) (filling the foraminifera's chamber)) but in different percents.

Micrite (microcrystalline calcite) is a descriptive term for a rock composed of fine-grained calcite crystal and particles formed in place or by the accumulation of fine-grained pre-existing carbonate material (Flügel, 2004). Micrite generally indicates low energy of deposition.

Foraminifera is an order belonging to the phylum Sarcodina and the class Rhizopoda, they are single-celled protists that live either on the sea floor or amongst the marine plankton. The shell (test) composed of secreted organic matter (tectin), secreted minerals (calcite or aragonite) or of agglutinated particles. This test consists of single chamber or several chambers each interconnected by an opening (foramen) or several openings (foramina). The group, which takes its name from these foramina, is known from early Cambrian times through to recent times. Foraminifera are important as biostratigraphic indicators in marine rocks of late Paleozoic, Mesozoic and Cenozoic age, largely because they are abundant, diverse and easy to study. The structure and composition of the test wall is important to the classification of the group. They were divided into suborder: Allogromiina (organic-walled), Textulariina (agglutinated tests), Miliolina, Fusulinina and Rotaliina (Calcareous tests) (Brasier, 1983).

Planktonic foraminifera evolved in the middle Jurassic and became major constituents of the marine plankton during the Cretaceous. They avoid terrigenous input. Their shells, therefore, accumulate in the bathyal depths of open marine basins. The planktonic foraminifera are absent or rare in shallow-marine environments. Planktonic foraminifera are abundant in fine-grained Cretaceous and Cenozoic carbonates deposited at the deep-sea bottom of open-marine settings (Flügel, 2004).

Planktonics live in the water column from the surface zone to depths of over 1000 m (Haq and Boersma, 1978). The superfamily Globigerinacea is belongs to planktonic foraminifera.

The classification of foraminifera found in this research belongs to:

Suborder: Rotaliina

Superfamily: Buliminacea

Family: Buliminidae

Superfamily: Globigerinacea

Family: Heterohelicidae

Family: Rotaliporidae?

The Buliminidae (benthic foraminifera) occur widely from shallow, coastal waters to the abyssal plain but are particularly abundant on the outer shelf and on the uppermost continental Slope (Haynes, 1985).

Heterohelicidae (Pelagic group) began its development in the Cretaceous (Chushman, 1940). This family appears to have been low oxygen tolerant (Keller, 2002).

Phosphate: marine phosphorite generally occurs in area of slow sedimentation. Upwelling currents are the popular mechanism to concentrate the phosphate in seawater into the sediments, upwelling currents lead to high organic productivities and phytoplankton growth in surface waters, which in turn results in organic-rich sediments and oxygen-deficient

waters overlying the sea floor. More organic matter, with its combined phosphorous and skeletal phosphate (bones) are thus contributed to the sea floor during these events. Most local upwelling does occur in regions of irregular sea-floor topography in response to regional current patterns. Many of the phosphorite deposits of the geological record formed when sea-level was relatively high or were associated with short-lived transgressions (Tucker, 2001).

Cement is a chemical precipitate from solution; it grows in pores, and requires supersaturation of the pore fluid with respect to the cement mineral (Flügel, 2004). The cement type in this facies belong to drusy cement (pore-filling cement), cement fill the foraminifera chambers.

The following are the microfacies types which are recognized in the study area (Jibal Ghuzayma) from bottom to top, the first four facies belong to Muwaqqar Formation and the last one belong to Um Rijam Formation. Depending on Dunhum's classification, these facies vary between (wackestone - packstone), while in Folk's classification it all follow (biomicrite)

1. Phosphatic foraminiferal micrite (wackestone).

   This microfacies represents many units with different thickness.

   - Unit one represents 3.5m (pl.1a). It composed is of phosphate particles (intraclasts (pl.1c&d), peloids and skeletal fragments (pl.6 a&b)) with

percent 13%, 49% of dark (bituminous) micrite and 38% of foraminifera belongs to the following families: Bulminidae (pl.5g), Heterohelicidae (pl.4a, b &d and pl.5a, b & c) and Rotaliporidae? (pl.5f), the foraminifera's chamber filled with mud and calcite cement (sparite) (drusy cement). There are other foraminifera in this facies but they are undefined; Trochospiral foraminifera (pl.7a).

- The concretion level two in unit one represents ~ 0.5 m It is composed of 6% Phosphate particles (intraclasts, peloids and skeletal fragments), 72% moderately dark micrite and 22% foraminifera (some are fragmented) belongs to following families: Bulminidae (pl.5g), Heterohelicidae (pl.4a &b and pl.5 a&b), the chambers filled with calcite cement (sparite) (drusy cement).

- Unit three represents 4.5 m (pl.2b). It composed of 4% of phosphate particles (intraclasts, peloids and skeletal fragments), 67% moderately dark micrite and 29% foraminifera belong to the following families: Bulminidae (pl.5g), Heterohelicidae (pl.4 a&g and pl.5 a&b) micrite and calcite cement (sparite) (drusy cement) filled the foraminifera's chamber. There are other foraminifera in this facies but they are undefined; Trochospiral foraminifera (pl.7b).

- Unit four represents 2 m (pl.2c). It composed of 11% phosphate particles (intraclasts, peloids and skeletal fragments), 63% dark micrite and 26% foraminifera belong to the following families: Bulminidae (pl.5g), Heterohelicidae (pl.4a&g pl.5 a&b), Rotaliporidae (pl.5f) and benthic genus (pl.5e), micrite and calcite cement (sparite) (drusy cement) filled the foraminifera's chamber.

- Unit six represents 60 cm (pl.3a). It composed of 11% phosphate particles (intraclasts, peloids and skeletal fragments), 51% of moderately dark micrite and 39% foraminifera belong to the following families: Bulminidae (pl.5g), Heterohelicidae (pl.4c, h&i and pl.5a&b), calcite cement (sparite) (drusy cement) filled the foraminifera's chamber. There are other foraminifera in this facies but they are undefined; (pl.7d) and Trochospiral foraminifera (pl.7c).

2. Laminated phosphatic foraminiferal micrite (packstone).

This microfacies represents many units with different thickness

- Unit two represents 4 m (pl.2a). It composed of 12% of phosphate particles (intraclasts, peloids and skeletal fragments), 40% dark (bituminous) laminated micrite and 48% foraminifera (some are fragmented) belong to the following families: Heterohelicidae (pl.4b&g and pl.5a&b) and Rotaliporidae? (pl.5f), the chambers filled with calcite cement (sparite)

(drusy cement).There are other foraminifera in this facies but they are undefined; (pl.7d) and Trochospiral foraminifera (pl.7b).

- Unit five represents 3.5 m (pl.2d). It is composed of 14% phosphate particles (intraclasts, peloids and skeletal fragments (pl.6c)), 48% dark laminated micrite and 38% foraminifera (some are fragmented) belong to the following families: Heterohelicidae (pl.4a&b and pl.5d) the chambers filled with calcite cement (sparite) (drusy cement). There are other foraminifera in this facies but they are undefined; (pl.7d&e) and Trochospiral foraminifera (pl.7c).

3. Foraminiferal phosphatic micrite (packstone).

- Unit seven represents 4 m (pl.3b). It composed of 51% of phosphate particles (intraclasts, peloids and skeletal fragments), 24% dark micrite and 25% foraminifera (highly fragmented) belong to the Heterohelicidae family (pl.4a&e and pl.5a&b), calcite cement (sparite) (drusy cement) filled the foraminifera's chamber.

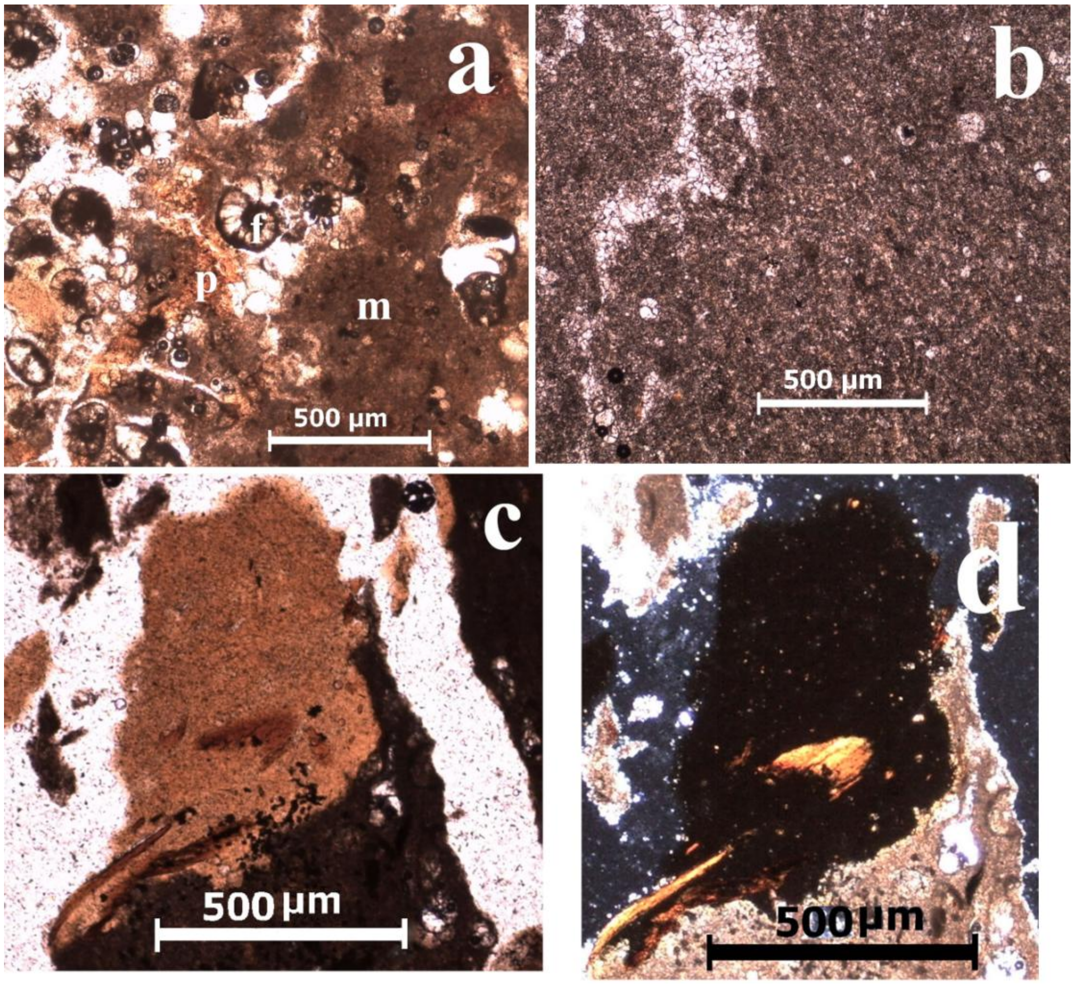
4. Phosphatic foraminiferal micrite (packstone).

   - Unit eight represents 4 m (pl.3c). It composed of 21% phosphate particles (intraclasts, peloids and skeletal fragments), 23% moderately dark micrite and 56% foraminifera belong to the Heterohelicidae family (pl.4e and pl.5a&b), foraminifera's chambers filled with micrite and calcite cement (sparite) (drusy calcite).

5. Foraminiferal micrite (packstone).

   - Unit ten represents 5 m of um Rijam Formation (pl.3d). It composed of 26% light micrite and 74% foraminifera (highly fragmented) belong to the following families: Heterohelicidae (pl.4f), Rotaliporidae? (pl.5f) and fragmented foraminifera belong to the Globigerinacea superfamily, calcite cement (sparite) (drusy calcite) filled the chambers. There are other foraminifera in this facies but they are undefined; (pl.7f, g &h).

Plate 1



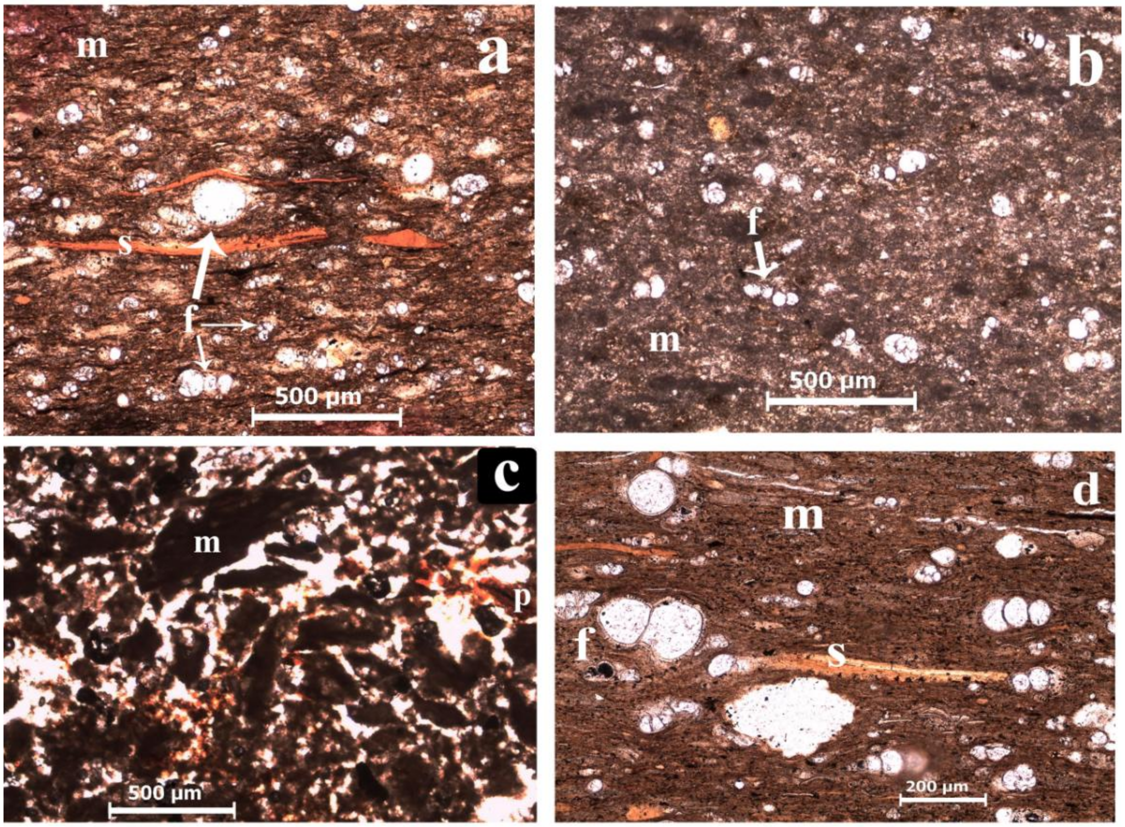
a) General view of the phosphatic foraminiferal micrite (wackestone) unit one. m: micrite, p: phosphate, f: foraminifera, (plane-polarized light (ppl)). Scale=500 µm

b) General view of the phosphatic foraminiferal micrite (wackestone), concretion level two, shows micrite. Scale=500 µm

c) Phosphate intraclast, (ppl). Scale=500 µm

d) Phosphate intraclast, (cross-polarized light (xpl)). Scale=500 µm

Plate 2



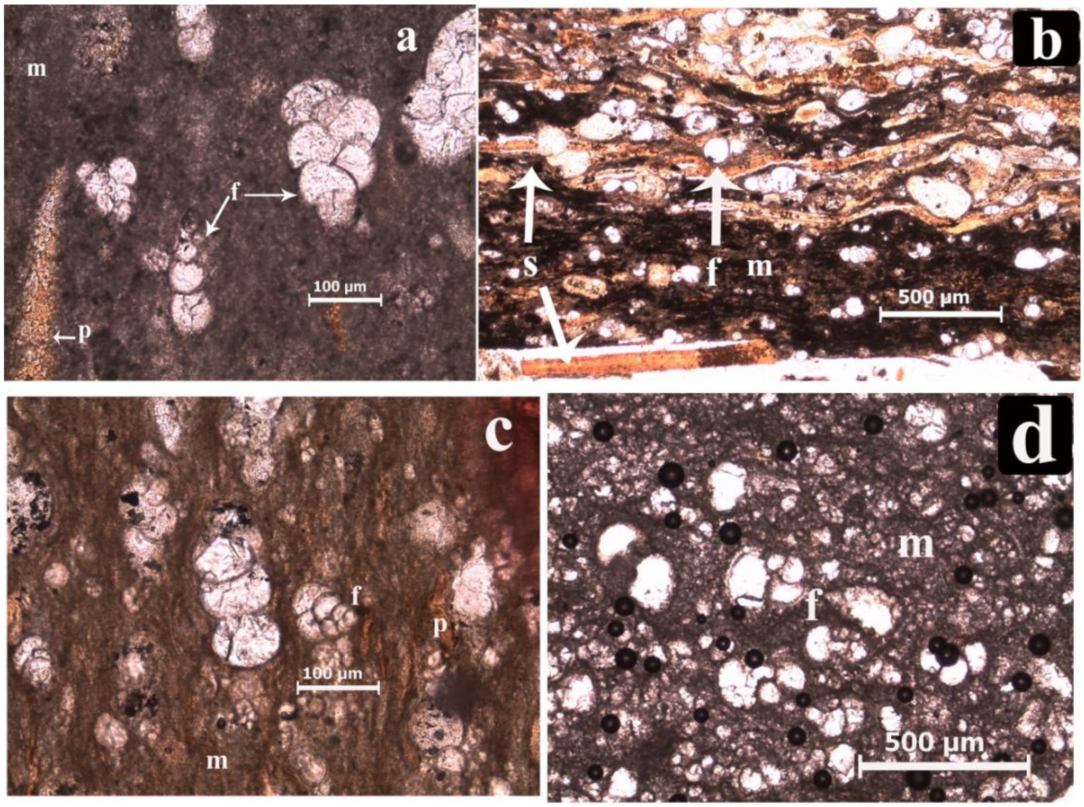
a) General view of the laminated phosphatic foraminiferal micrite (packstone), unit two. m: micrite, f: foraminifera, s: skeletal fragments of phosphatic particles, (ppl). Scale= 500 µm.

b) General view of the Phosphatic foraminiferal micrite (wackestone), unit three, m: micrite, f: foraminifera, (ppl). Scale=500 µm.

c) General view of the Phosphatic foraminiferal micrite (wackestone), unit four, m: micrite, p: phosphate particles, (ppl). Scale= 500 µm.

d) Laminated phosphatic foraminiferal micrite (packstone), unit five, m: micrite s: skeletal fragments phosphate particles, f: foraminifera (ppl). Scale=200 µm.

Plate3:



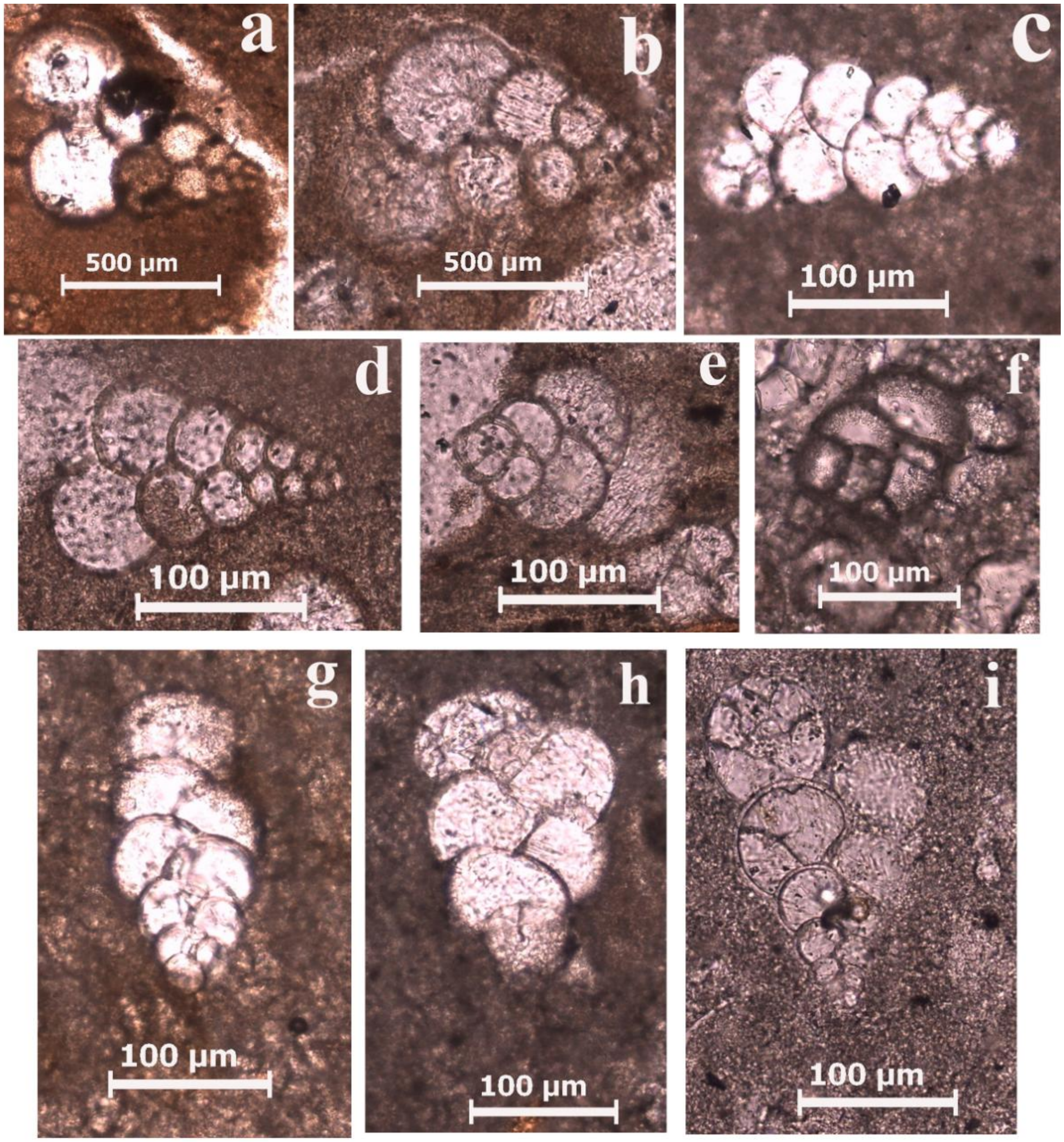
a) General view of the phosphatic foraminiferal micrite (wackstone), unit six, m: micrite, f: foraminifera, p: phosphate particles, (ppl). Scale=100 µm.

b) General view of the foraminiferal phosphatic micrite (packstone), unit seven, s: skeletal fragments of phosphate particles, m: micrite, f: foraminifera, (ppl). Scale= 500 µm.

c) Phosphatic foraminiferal micrite (packstone), unit eight, m: micrite, f: foraminifera, p: phosphate particles, (ppl). Scale= 100 µm.

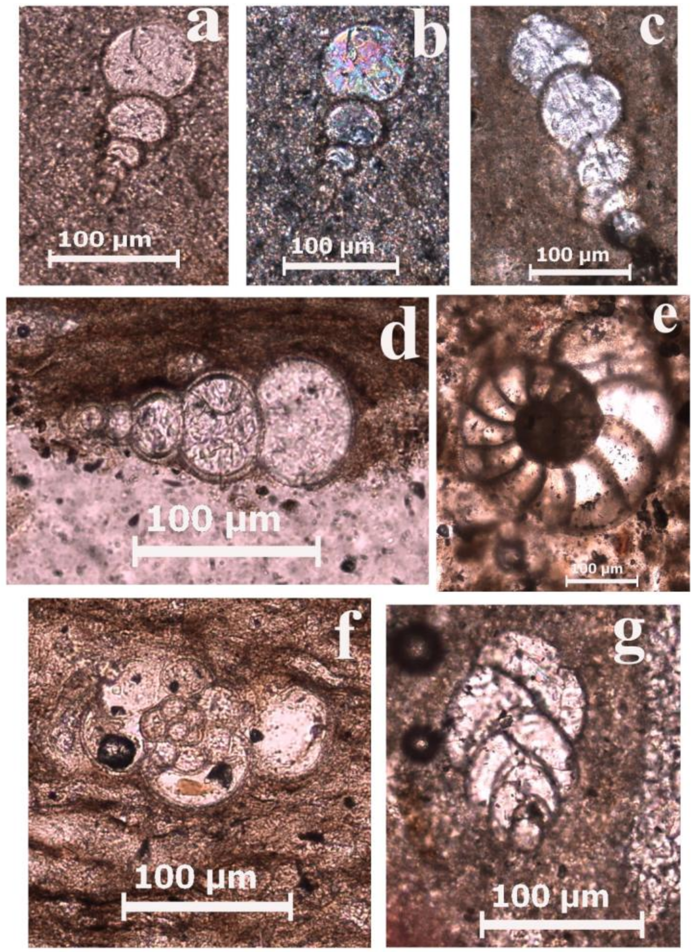
d) Foraminiferal micrite (packstone), unit ten, m: micrite, f: foraminifera, (ppl). Scale= 500 µm.

Plate 4:



a-i) Biserial planktonic foraminifera (Heterohelicidae family) (ppl). Scale (a&b)=500µm, scale (c-i)=100µm

Plate 5:



a&d) Uniserial planktonic foraminifera (Heterohelicidae family) (ppl).Scale=100µm

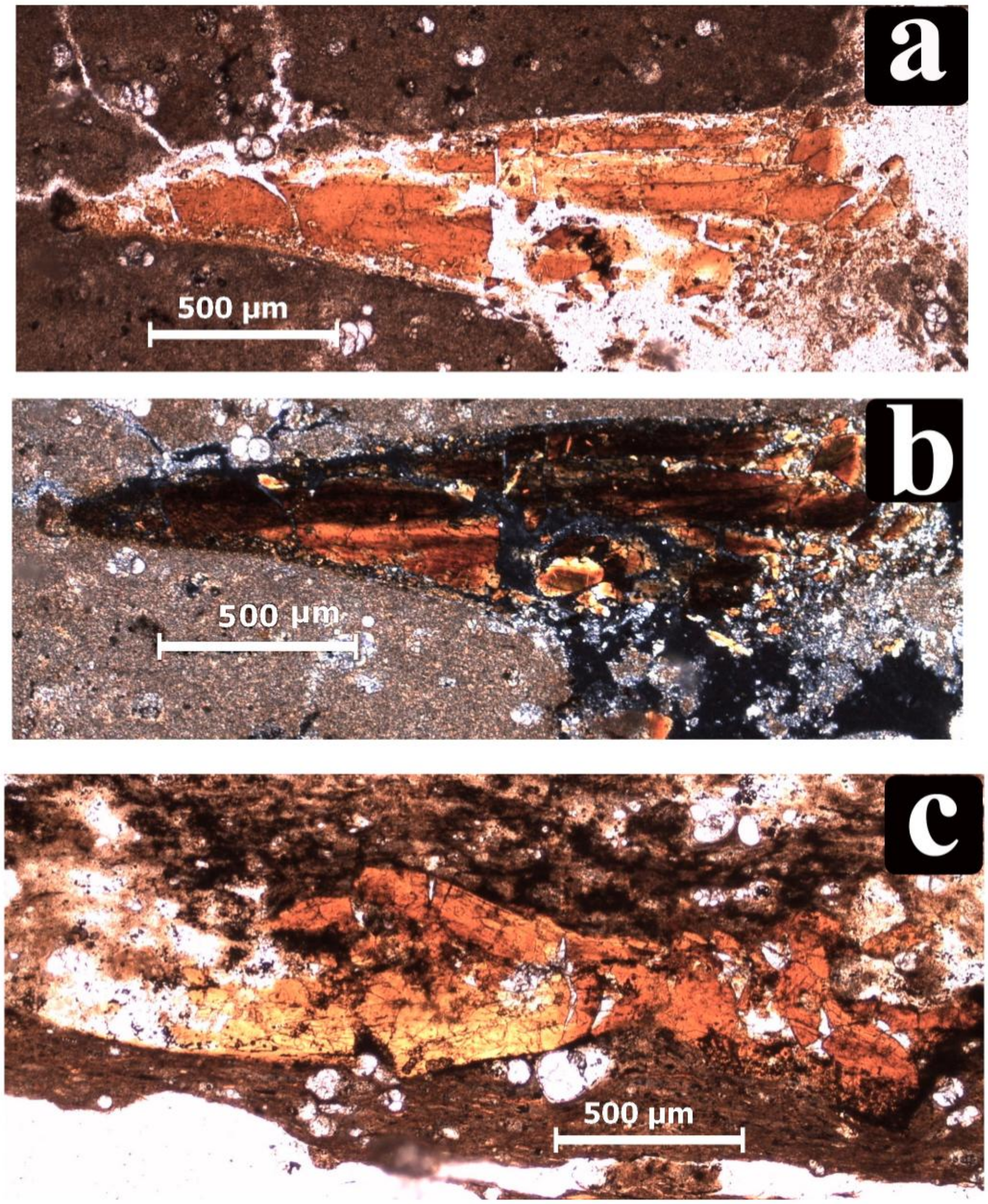
b&c) Uniserial planktonic foraminifera, the chambers filled with calcite, (Heterohelicidae family) (xpl). Scale=100µm.

e) Trochospiral benthic foraminifera (*Rosalina* genus) (ppl). Scale=100µm.

f) Trochospiral planktonic foraminifera (Rotaliporidae?) (ppl).scale=100µm.

g) Biserial foraminifera (Buliminidae family) (ppl). Scale= 100µm.

Plate 6:

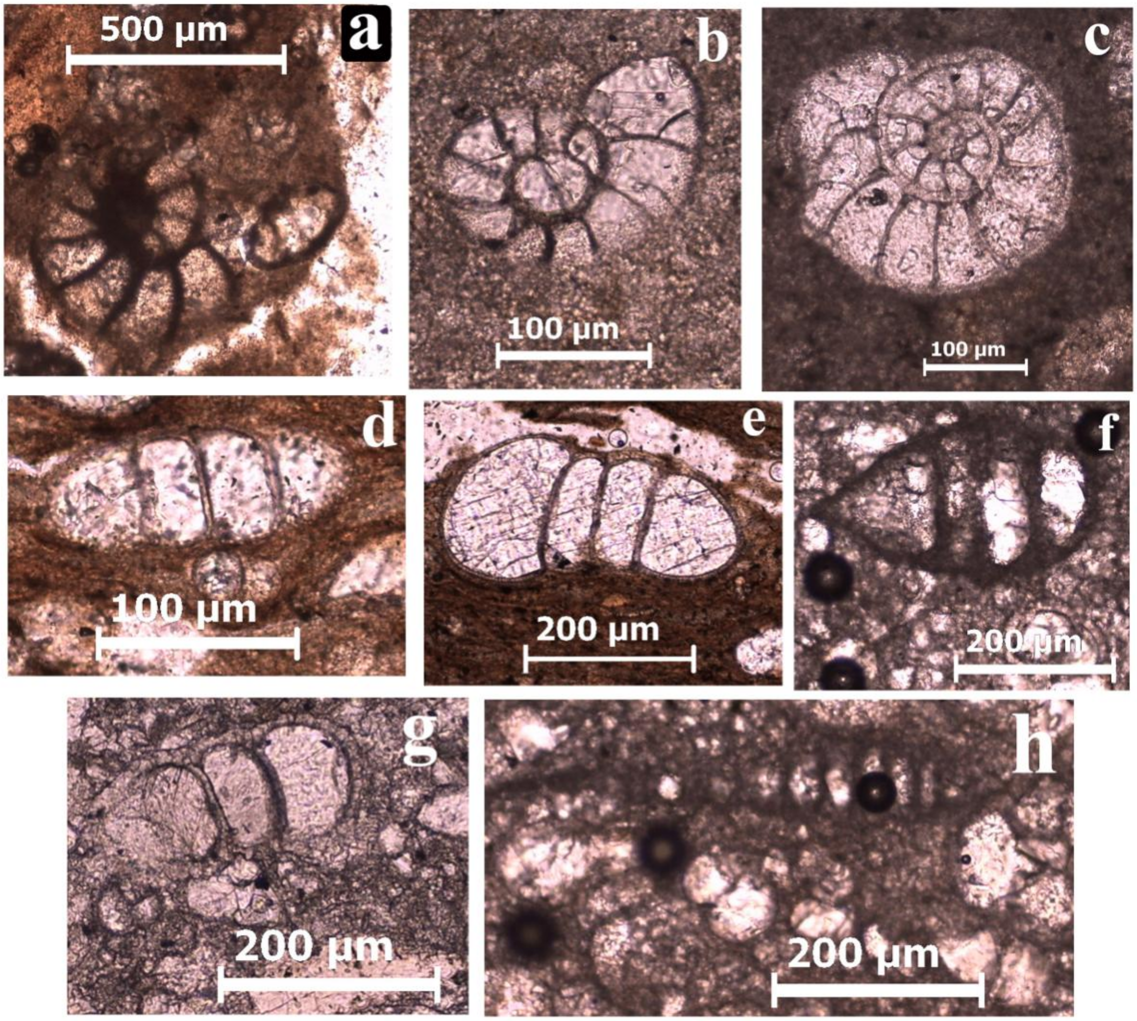


a) phosphate particle, skeletal fragments (ppl). Scale=500µm.

b) Phosphate particle, skeletal fragment (xpl). Scale=500µm.

c) Phosphate particle, skeletal fragment (ppl). Scale=500µm.

Plate 7:



a-c) Undefined trochospiral foraminifera. (ppl). Scale (a) =500µm, (b&c) =100µm.

d-h) Undefined foraminifera. (ppl). Scale (d) = 100µm. (e-h) = 200µm.

Chapter five

Discussion and Conclusions

5.1 Discussion:

The Upper Cretaceous (Cenomanian-Maastrichtian) in Jordan is represented by Ajlun and Belqa Groups. The study area (Jibal Ghuzayma) incorporates sedimentary rocks belonging to Belqa Group (Muwaqqar and Um Rijam Formations).

5.1.1 Microfacies study

The microfacies study carried out on the sediments of upper part of Muwaqqar Formation (28.6 m) and Um Rijam Formation (4.4 m), these 33 m were studied and divided into 10 units and 6 concretion levels. These units consist of phosphatic bituminous chalk marl, bituminous chalk marl, marly limestone, limestone, chalk marl, marl and chalky limestone, (see figure 2.1).

Microfacies study resulted in the recognition of five microfacies types, summarized in table (5.1).

Table 5.1: the identified microfacies and their thicknesses.

MF-no	Microfacies Name	Thicknesses (m)
1	Phosphatic foraminiferal micrite (wackestone)	3.5 - 0.5 - 4.5 - 2 - 0.6
2	Laminated phosphatic foraminiferal micrite (packstone)	4 - 3.5
3	Foraminiferal phosphatic micrite (packstone)	4
4	Phosphatic foraminiferal micrite (packstone)	4
5	Foraminiferal micrite (packstone)	5

This facies in general is composed of phosphate particles, micrite and foraminifera.

The presence of micrite generally indicates low energy deposition. The presence of phosphate particles indicate marine environments with slow sedimentation, and they are deposited when the sea-level was relatively high, (Tucker, 2001). Phosphate concentrates from seawater into the sediments by the upwelling currents, upwelling currents lead to high organic productivities and phytoplankton growth in surface waters, which in turn results in organic-rich sediments and oxygen-deficient waters overlying the sea floor.

Foraminifera: there are planktonic and benthic foraminifera, the Heterohelicidae family are planktonic foraminifera indicate pelagic (open marine) environments with low oxygen (Keller, 2002). The Buliminidae family which is benthic group exists in some of the facies, occur widely from shallow, coastal waters to the abyssal plain but are particularly abundant on the outer shelf and on the uppermost continental slope, (Haynes, 1985). The presence of the benthic foraminifera indicates that the sea floor was containing oxygen, but the presence of the organic matter indicates that there was oxygen-deficient in seawater.

The presence of large quantity of planktonic foraminifera and micrite in Muwaqqar Formation more than the undeerlying formations (Al-Hisa and Amman Formations) indicates that the sea-level was relatively high (the sea-level rose).

5.1.2 Fossils

One of the major goals of this thesis is to identify and classify the ammonites to the species level. Three species of ammonites were recorded in the upper part of Muwaqqar Formation in the uppermost concretion level, (see figure 2.1).

Two planispiral species belong to the family Sphenodiscidae (Hyatt, 1900); *Sphenodiscus lobatus* (Tuomy, 1856) and *Libycoceras ismaeli* (Zittle, 1895).

The third one (straight species) belongs to Baculitidae family (Meek, 1876); *Baculites sp.* (Lamark, 1799).

Sphenodiscid Ammonites were widespread during the Maastrichtian, with records from localities in Africa, Europe, both Americas, Poland, Bulgaria and Madagascar it is known from Upper Cretaceous age, it is known from Lower Maastrichtian in India and Mexico, (see table 3.3).

Depending on the previous data we conclude that the depositional environment of the study area is **deep-water basin** (according to standard facies zone of the modified Wilson model (1975)) (Flügel, 2004).

Deep-water basin of Wilson model, (Flügel, 2004):

Setting: below wave base, below the euphotic zone. Water depth about 30 m to several 100 m. wide facies belt.

Sediments: hemipelagic muds very common. Sometimes common cherts. Anoxic conditions fairly common (high organic content; lack of bioturbation). Dark thin limestone beds and dark shale beds. Lime mudstones, calcisilties. Rock color: dark brown and black (due to organic matter) and reddish (due to slow sedimentation).

Biota: predominantly nekton (e.g. ammonites) and plankton (radiolarians, pelagic foraminifera, calpionellids, coquinas of thin-shelled bivalves). Occasionally benthos (abundant sponge spicules).

Common lithofacies: lime mudstone, wackestone, packstones. Marls.

5.2 Conclusions:

1. Jibal Ghuzayma (study area) incorporates sedimentary rocks belonging to Belqa Group (Muwaqqar and Um Rijam Formations); it was divided into ten units composed of: phosphatic bituminous chalk marl, bituminous chalk marl, marly limrstone, limestone, chalk marl, marl and chalky limestone.

2. From the microfacies analysis study we conclude :

   a) Five microfacies types were identified from the petrographical studies of the samples collected from Jibal Ghuzayma.

   b) The identified microfacies are: phosphatic foraminiferal micrite (wackestone), laminated phosphatic foraminiferal micrite (packstone), foraminiferal phosphatic micrite (packstone), phosphatic foraminiferal micrite (packstone), foraminiferal micrite (packstone).

3. The presence of large quantity of planktonic foraminifera, micrite and phosphate particles in Muwaqqar Formation more than the underlying formations (Al-Hisa and Amman Formations) indicates sea level rise.

4. The presence of the benthic foraminifera indicates that the sea floor was containing oxygen, but there was oxygen-deficient in seawater.

5. According to standard facies zone modified from Wilson model (1975), the depositional environment of the study area is **deep-water basin.** Indicated by the presence of micrite, phosphate particles, planktonic foraminifera and ammonites.

6. Three ammonites species were identified from Jibal Ghuzayma belongs to the upper part of Muwaqqar Formation;

a) ***Spenodiscus lobatus*** (Tuomy, 1856), ***Libycoceras ismaeli*** (Zittel, 1895) and ***Baculite*** sp. (Lamark, 1799).

b) Correlation of this species with different localities, Africa, Europe, both Americas, Poland, Bulgaria, Madagascar, India, Mexico, Algerian Sahara, North Africa, Niger, Egypt and East Jordan, indicates Maastrichtian age.

c) The presence of Sphenodiscidae Ammonites indicates a shallow (not restricted) marine environment.

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أمونايت الكريتاسي المتأخر (تكوين الموقر) في جنوب الأردن

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ملخص

أجريت دراسة للمستحاثات الدقيقة والامونيت والسحنات الدقيقة والبيئات القديمة في منطقة جبال خزيمة الواقعة جنوب شرق عمان. حيث تضمن العمل الميداني جمع عينات الامونيت وعينات صخور من المقطع المتكشف بالاضافة الى رسم المقطع الجيولوجي للمنطقة الذي تكون من 33 م من تكويني موقر وام رجام.

اظهرت دراسة السحنات الدقيقة لرواسب تكوين موقر في تكشف مقطع جبال خزيمة خمس سحنات دقيقة ترسب معظمها في بيئه بحرية عميقة قليلة الاكسجين ومكونة من الفوسفات والمكريت والفورامنيفيرا الطافية والقاعية. إن وجود الفورامنيفيرا الطافية بكثرة مقارنة بالتكاوين الواقعة اسفل تكوين الموقر يدل على وجود تقدم بحري في تلك الفترة الزمنية.

تم تمييز عائلتين من الفورامنفيرا الطافية وعائلة من الفورامنفيرا القاعية

Heterohelicidae and Rotaliporidae? (planktonic) and Buliminidae (Benthic)

كما تمت دراسة ثلاثة أنواع من الامونيت الدالة على عمر الماسترختي لهذا التكوين وهي:

***Spenodiscus lobatus* (Tuomy, 1856), *Libycoceras ismaeli* (Zittel, 1895) and *Baculite sp.* (Lamark, 1799).**